

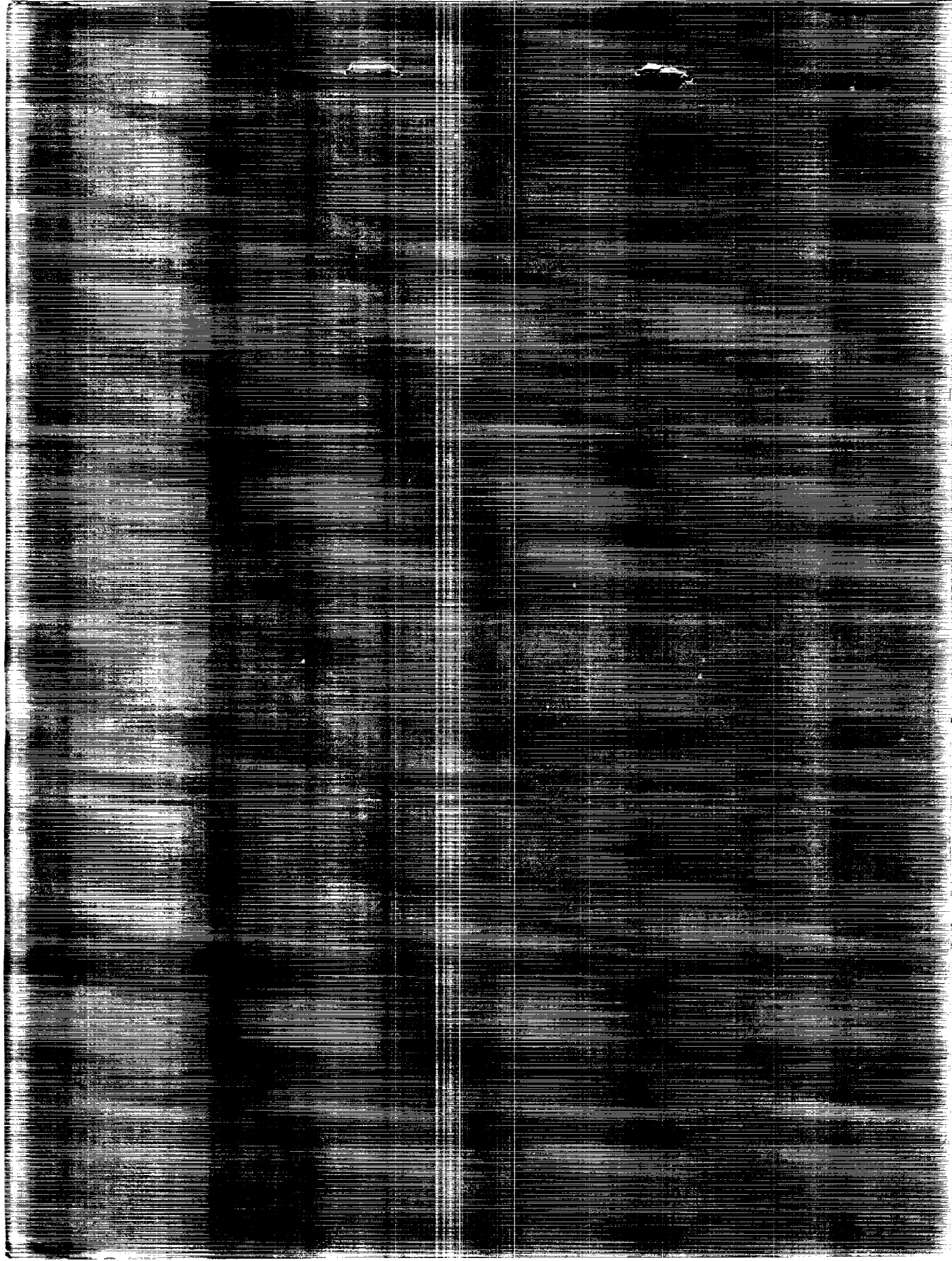
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NASA Information Sciences and Human Factors Program

Annual Report, 1989

NASA Office of Aeronautics and
Exploration Technology

Information Sciences and Human
Factors Division



National Aeronautics and
Space Administration
Office of Management
Scientific and Technical
Information Division

1990

Introduction

The Information Sciences and Human Factors (IS&HF) Division is one of five divisions which comprise NASA's Office of Aeronautics and Exploration Technology (OAET). This division sponsors research in both aeronautical and space technology. This report documents the most significant accomplishments during the past year. Each year, this report is prepared to serve as the primary mechanism for coordinating NASA activities with industry and industrial IR&D managers. This document is also intended to communicate significant technical accomplishments to NASA technologists, project engineers, other government agencies, and academia.

The IS&HF Program consists of seven major elements: Automation and Robotics, Computer Sciences, Communications, Controls and Guidance, Data Systems, Human Factors, and Sensor Technology. Accomplishments are presented in all seven categories. Controls and Guidance and Human Factors are shown in two sections, Space and Aeronautics. Total program funding, including civil service manpower costs, for fiscal year 1989 is shown below.

Element	Aero (\$M)	Space (\$M)	Total R&D (\$M)
Automation & Robotics		45.8	45.8
Communications		12.3	12.3
Computer Sciences	14.7	4.4	19.1
Controls & Guidance	47.5	10.1	57.6
Data Systems		14.8	14.8
Human Factors	16.5	7.3	23.8
Sensor Technology		19.5	19.5

The NASA Pathfinder Program was initiated in fiscal year 1988 with the goal of providing a strong technology foundation for the nation's future space missions. The IS&HF Division has focused Pathfinder technology activities in Planetary Rover Technology, Human Factors/EVA suit, Automated Rendezvous and Docking, and Adaptive Hazard Avoidance Landing. Funding for these activities is included above. In fiscal year 1990, it is anticipated that more focused activities in Space Exploration technologies will be initiated.

Within the Base Aeronautics Human Factors Program, focused efforts in Aviation Safety/Automation were initiated in fiscal year 1989. The objectives of this program include the development of human-centered automation concepts for use in future transport aircraft and air traffic control (ATC) stations. The integration of highly automated aircraft into the future ATC system also will be addressed in this program augmentation. Beginning in fiscal year 1990, the Airborne Wind Shear Detection and Avoidance research efforts will be augmented to allow flight evaluation of Doppler radar, lidar, and infrared sensors.

To aid in the communication of program efforts, the names and phone numbers of Headquarters program managers are included in this report along with the names and phone numbers of the key center technologists who conducted or managed the significant technology activities.

Division Director: Lee Holcomb
(202) 453-2747

Deputy Director: Ray Hood
(202) 453-2745

NASA Directory

Center	Symbol
Ames Research Center Moffett Field, CA 94035	ARC
Ames Research Center Hugh L. Dryden Flight Research Facility PO Box 273 Edwards, CA 93523	DFRF
Goddard Space Flight Center Greenbelt, MD 20771	GSFC
Headquarters NASA/OAET/RC Washington, DC 20546	HQ
Jet Propulsion Laboratory 4800 Oak Grove Drive Pasadena, CA 91109	JPL
Lyndon B. Johnson Space Center Houston, TX 77058	JSC
John F. Kennedy Space Center Kennedy Space Center, FL 32899	KSC
Langley Research Center Hampton, VA 23665	LaRC
Lewis Research Center 21000 Brookpark Road Cleveland, OH 44135	LeRC
George C. Marshall Space Flight Center National Aeronautics and Space Administration Marshall Space Flight Center, AL 35812	MSFC

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Automation and Robotics

OAET created the Civil Space Technology Initiative (CSTI) to improve NASA space technology. Of particular concern has been the cost of NASA ground and flight operations, such that the CSTI program has focused significant resources on development and demonstration of automation and robotics technologies for space applications. Artificial Intelligence and Telerobotics, when applied to the space environment, have the capability to significantly improve productivity and enhance safety, as well as reduce the cost of NASA operations.

The Automation and Robotics Program is divided into two areas, with the Autonomous Systems focusing on automation for in-space servicing, assembly, and repair. Applications demonstrations are planned at NASA mission centers for the transfer of the technology into the operations environment. Underlying the demonstrations are five research areas that will develop expertise in sensing and perception, planning and reasoning, control execution, operator interface, and systems architecture and integration.

The Telerobotics Program has achieved its first major technology demonstration through the vision-based de-spin of a spinning satellite (once it is initialized by a human-guided graphic overlay). Three applications demonstrations were completed using the Beam Assembly Teleoperator. These applications were: assembling beam elements into a space structure; using a general control structure for coordinated movement of multiple robot arms; and using the Oak Ridge National Laboratory's teleoperated manipulator to recreate the ACCESS experiment. The Autonomous Systems Program has progressed towards the Space Station Thermal Control Expert System technology demonstration. We have developed an operational readiness prototype expert system for the monitoring of the Space Shuttle communications systems and initial integration of the KATE and GMODS for diagnostics and control of the Shuttle Environmental Control System. Also, we developed an expert system for aiding the communications officer in the Space Shuttle Mission Control Room. This system was first operationally used on STS-26.

Major research goals were accomplished in the areas of operator interface, systems architecture and integration, and planning and reasoning. In the operator interface element, higher performance force-reflecting hand controllers and triggers were tested for teleoperation. In the planning and reasoning element, a collaborative effort with DARPA began on research of intelligent communicating agents, while the Autoclass probabilistic reasoning system produced striking new classes of spectral objects when applied to Infrared Astronomical Satellite (IRAS) data.

In addition to the CSTI technologies, OAET has been reviewing the technology requirements for future planetary and lunar missions and has packaged these into the initiative called Pathfinder. In the area of exploration a significant amount of automation and robotics research will be focused on the development of a planetary rover that would act in the place of humans in the scientific discovery of the Moon and Mars semi-autonomously, with only occasional communication and direction from Earth. This is a challenging problem in that the rover would effectively be a mobile laboratory with its own instrumentation, tools, and intelligence for self-navigation and rock sample acquisition and analysis. This development effort is a requirement unique to NASA, and it will build on the in-house expertise in automation and robotics which has resulted from the CSTI program.

Program Manager: Melvin Montemerlo
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Comparison of Joint Space Versus Task Space Force-Load Distribution Optimization for Multiarm Manipulator System

The objective of this research was to evaluate the cost effectiveness of force-load distribution derived in Cartesian space and in joint space.

There are a number of ways to choose the force distribution for multiple arms grasping a single object. Usually load distributions are determined by maximizing a performance index, such as power required. The performance index has been formulated in terms of joint space and also in Cartesian space. The two are compared for manipulator power and the computational cost.

A simulation using the parameters of the LaRC Laboratory Telerobotic Manipulator (LTM) moving a 40-lb payload on Earth was used to determine power consumption. Computational cost was based on the Harris 80C86 radiation-hardened processor.

The simulation showed a 2-percent power savings (25 W) using the joint space formulation. However, the joint computations were approximately 15 times slower than the Cartesian formulation. Adding an additional processor board to increase computational speed would require additional power of approximately 30 W for the simulated task.

Based on the results obtained, it appears wise to develop force distribution software in Cartesian space. Results will be simpler and easier to visualize and can be obtained at no additional cost.

Technical Contact: Donald I. Soloway, LaRC, (804) 864-6681

Power Versus Computational Cost

Given desired force F and matrix Λ , output torque is computed as:

$$\tau = \Lambda F$$

Computation can be done in Cartesian space or joint space.

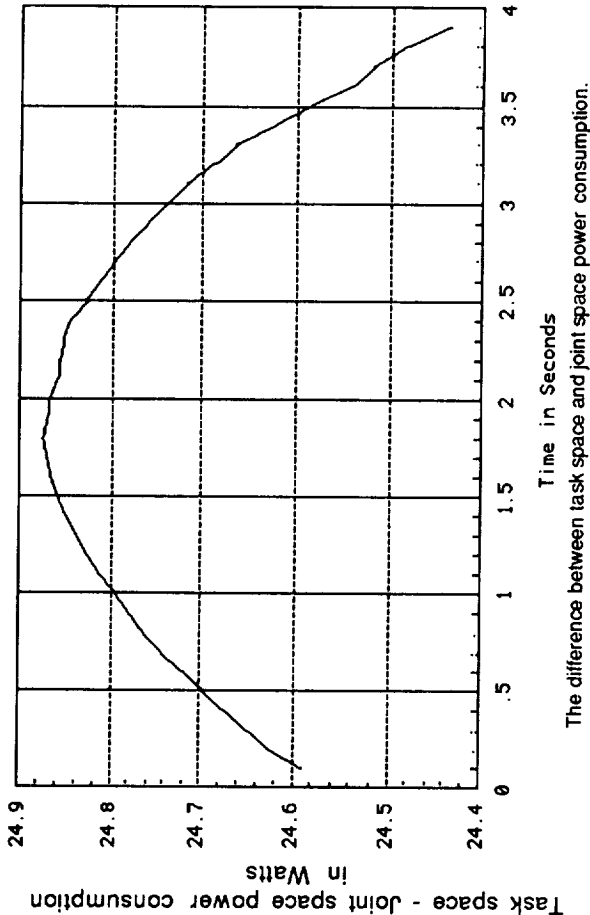
$\tau_C^2 > \tau_J^2$, more torque is required in Cartesian space,
 $\Lambda_C < \Lambda_J$, but computational costs are lower in Cartesian space.

Number of Arms

Degrees of Freedom	Number of Arms			
	2	3	4	
	6	29.8	21.9	17.3
	7	27.4	19.5	15.6
Joint Space Computation Speed (Hz)	8	25.0	18.1	14.2

Number of Arms

Desired force components	Number of Arms			
	2	3	4	
	6	413	275	206
	7	413	275	206
Task Space Computation Speed (Hz)	8	413	275	206



Autonomous Systems - Mission Operations Automation

The objective of the Autonomous Systems RTOP at JSC is to improve the quality of flight decision making and the cost-effectiveness of Space Shuttle Mission Control Operations. This can be accomplished by introducing state-of-the-art techniques in expert systems, software engineering, human/computer interface, and distributed systems into the Space Shuttle Mission Control Center (MCC). This RTOP has produced three operational expert systems which are being used as primary tools during Space Shuttle missions.

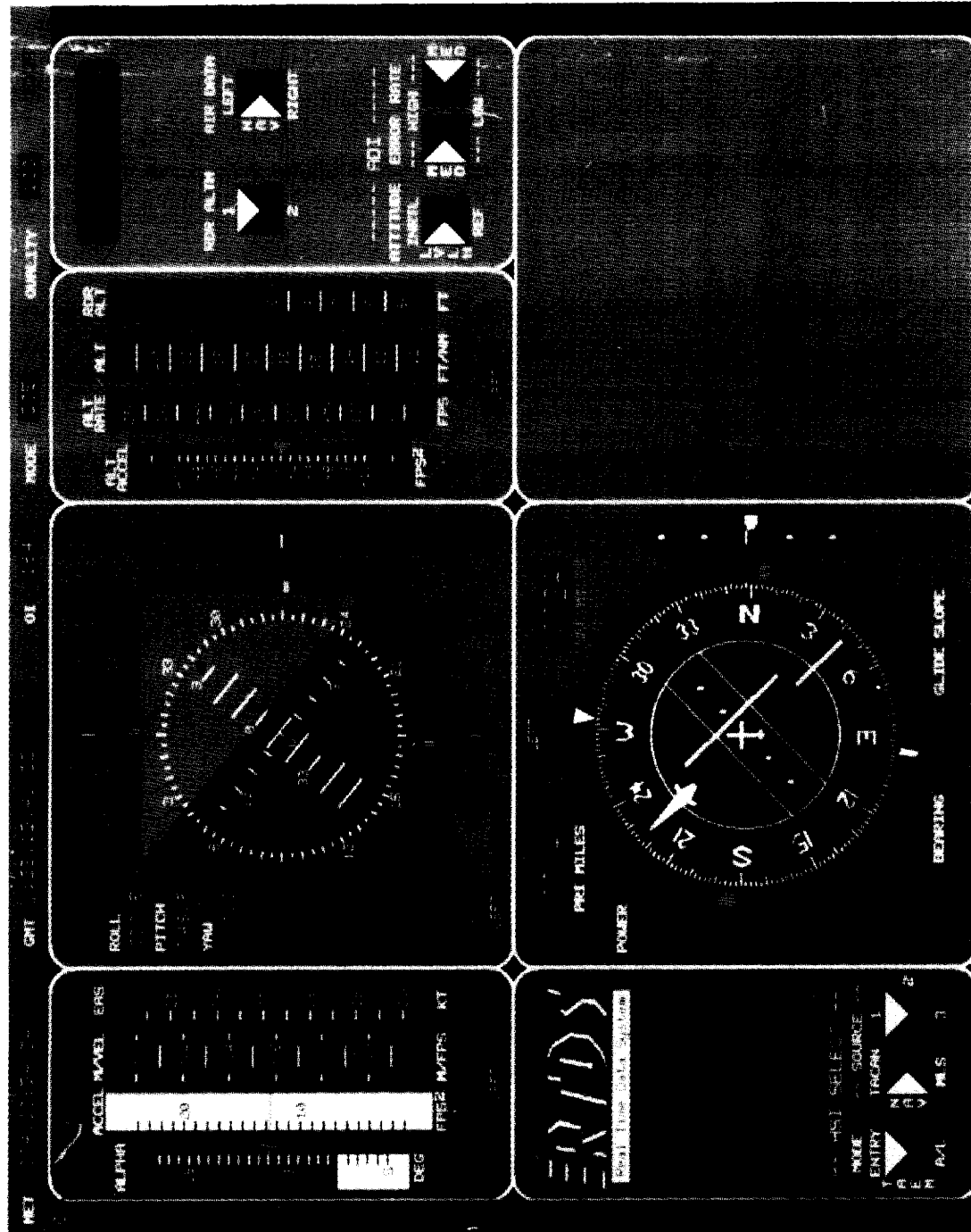
At the start of this RTOP in 1987, Mission Control relied entirely on a mainframe architecture from the early 1970's that provided no automated monitoring and used a monochrome text-display terminal as the human computer interface. This system was unable to accommodate automation, such as expert systems, which can provide better quality decision making, lower training times, and manpower reductions. Under this RTOP, three real-time expert systems have been introduced into Mission Control (Communications, Main Engines, and Mechanical) which have dramatically increased the quality of telemetry monitoring. These state-of-the-art systems have completely replaced some of the older consoles. In fiscal year 1990, these systems will allow some manpower reductions in the flight control teams. Superior software engineering tools introduced in these three expert systems have also allowed Mission Operations to clear a backlog of previously unimplemented requirements at a significant cost reduction. These unimplemented requirements were estimated to cost over \$2 million to implement in the mainframe and have been implemented at no additional cost as part of the expert system effort. A productivity gain of at least 10:1 in workstation development over mainframe development is estimated.

This RTOP has introduced state-of-the-art expert system building tools, color-graphic workstations, telemetry systems, data recording, and software engineering techniques into the Mission Control Center. All equipment and a large number of the software tools have been procured from commercial off-the-shelf sources and represent the first significant introduction of new technology into the Mission Control Center in the 1980's. The quality of this work was recognized by the American Association for Artificial Intelligence when it named the project one of the 25 most innovative applications of AI in the United States in 1989. This effort was recognized by NASA with a Space Act award for significant innovation. Software and techniques developed under this project have been transferred to the USAF Flight Test Center and to the ARC/DFRF and are being used in aeronautics flight-testing. Tools developed under this project have been baselined into the Space Station Control Center.

The project is currently being expanded to cover all Space Shuttle subsystem disciplines. Scheduled for this year are Guidance, Navigation and Control, On-Orbit Propulsion, Remote Manipulator System, Electrical Power, Life Support, and Spacelab Systems. As each system is developed, it will first operate in parallel with the conventional system, and then it will replace the conventional system after being tested in flight. In 1990, an Orbital Maneuvering Vehicle Expert System will be built that will include the incorporation and analysis of real-time remote television images as well as real-time telemetry data.

Technical Contact: Troy Heindel, JSC, (713) 483-2639

Autonomous Systems - Real-Time Data Systems



Robotic Task Evaluation

Telerobotics is an emerging technology for performing many different tasks in hazardous or remote situations. A major factor in the development and application of these telerobotic systems is determining how well they perform the designated tasks. This is evaluated primarily by means of time, error counts, and operator opinions.

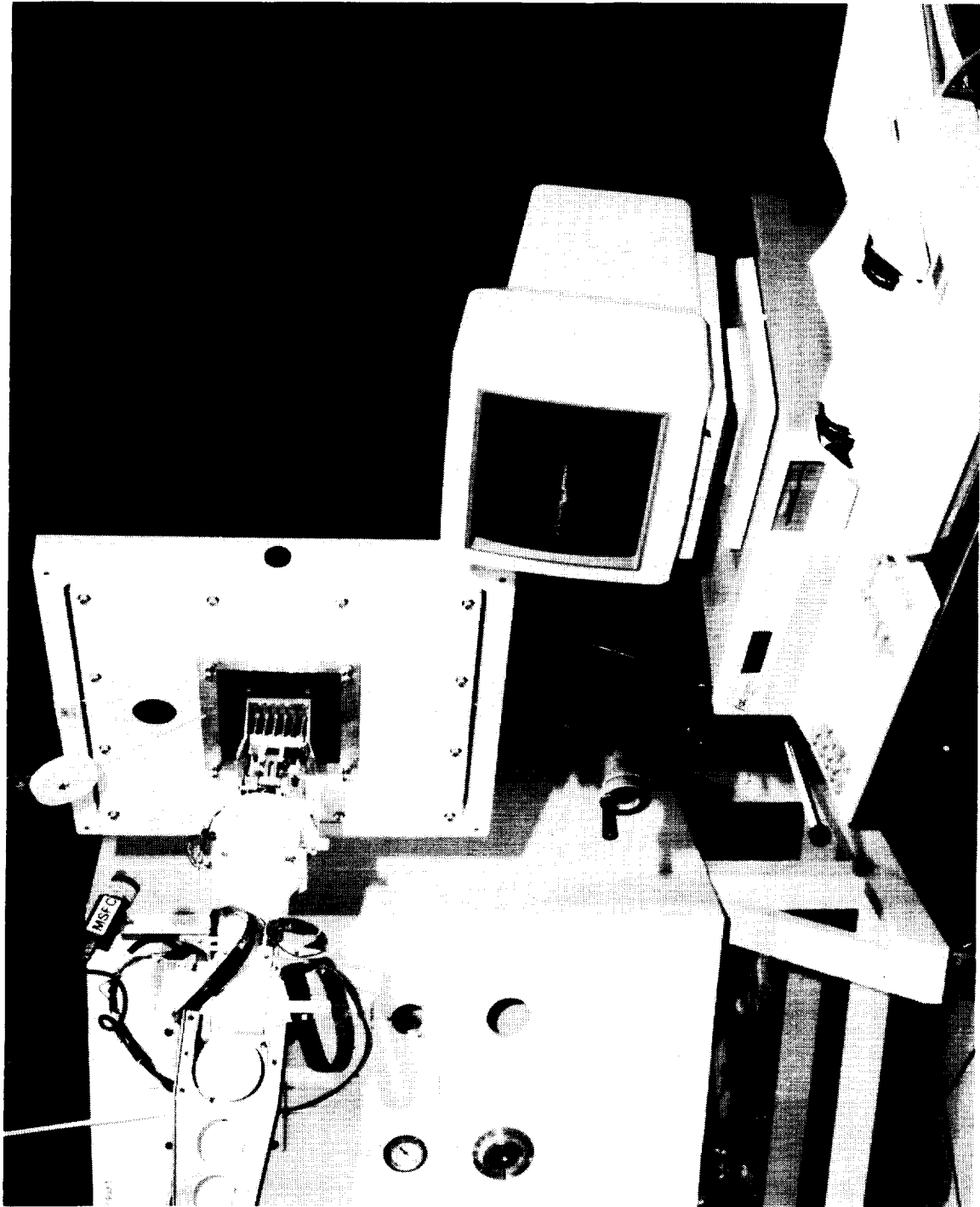
The current evaluation approach is inadequate for evaluating complex telerobotic systems with higher levels of autonomy (less teleoperation) and more critical task interfaces. To develop a methodology for task performance evaluation, it is necessary to measure forces, motions, and joint parameters in real time while performing realistic tasks that are analyzed and decomposed to compare actual to optimal performance. Additionally, this methodology can be used as a metric for telerobotic systems by the incorporation of graduated evaluation tasks or as a means to evaluate individual task interface designs on a representative telerobotic system.

MSFC has an ongoing development program to address relevant issues for task evaluation. The current emphasis of the program is to refine a computerized force-torque frame sensor with three-dimensional position sensors; to incorporate robot joint sensing for measurement; to develop methods of robot evaluation based on simulated robotic motions and forces versus real-time measurements; to incorporate standard task test articles selected from ongoing programs; and to define the methodology of using CAD data and operation sequences to perform piecewise decomposition of a given task and correlation of an optimal path to measured robot motion.

The data collection system is under calibration in the Flight Robotics Laboratory and current tasks are to be analyzed via FTS Task Analysis Methodology for comparison to real-time measurements. Efforts are ongoing to select and incorporate standardized test articles as well as program specific tasks. Detailed robotic simulation and analysis tools will be studied for generating optimal task performance profiles.

Technical Contact: E. C. Smith, MSFC, (205) 544-3506

Robotic Calibrated Task Board



Anthropomorphic Telerobot With Full-Force Reflection

This task is focused on the design and prototype development of an anthropomorphic master-slave telemanipulator system. Both the master and slave arms have 7 degrees-of-freedom (dof) in human-like configuration: 3 dof at the shoulder, 1 dof at the elbow, and 3 dof at the wrist. Each human-like hand has a thumb and 3 fingers, with each finger having 4 dof; knuckle joints are used at the finger base allowing motion in two different directions. The master arm is an exoskeletal device strapped to the operator's arm. The master hand is a glove-type exoskeleton strapped to the operator's hand and fingers, leaving the inner part of the fingers and the palm free. The mechanization of control (hybrid position/force control) at all master and slave arm/hand joints mimics the muscle's dual function as a positioner and stiffness adjuster. This also implies force reflection to the operator. The control electronics of this prototype master-slave arm/hand system is derived from and leveraged with ongoing Code RC sponsored "ESAB/SMART HAND" control electronics work, under the Control Execution task in the Automation & Robotics RTOP, because of the inherent similarities between the two control electronics systems. The final goal is to develop an anthropomorphic dual arm/hand system providing telemanipulation capabilities equivalent to the manipulative capabilities of a two-handed Extravehicular Activity (EVA)-suited astronaut.

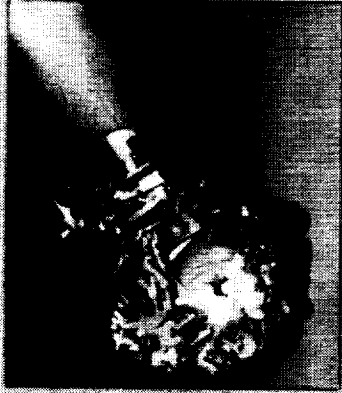
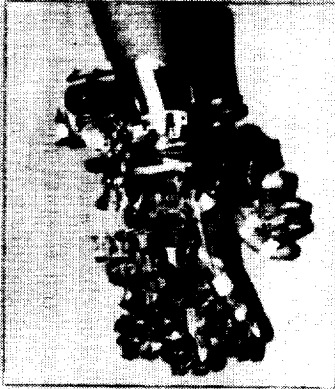
Dexterous, man-equivalent telemanipulation capability for complex, sensitive, and unstructured servicing tasks in space are recognized long-range NASA needs. The anthropomorphic master-slave telemanipulator system under development will enable the performance of EVA-type versatile manipulation tasks that require redundancy in arm and human-like dexterity in hand functions. This system provides a natural, man-rated "telepresence" through a high-fidelity operator/control response capability in a complex, 92-dof dual-arm/hand, master-slave telemanipulator mechanism. The key technical point of this system is the natural man-machine interface that enables easy real-time performance of complex and sensitive tasks, temporarily sidestepping unresolved and very complex control-programming issues for the control of high-dof autonomous telerobot arm/hand systems.

Accomplishments include the completion of the improved engineering design of the master arm/hand system, 95-percent completion of the fabrication of the master arm and master glove-hand, including the gravity counterbalance, and procurement of control electronics for shoulder and elbow drives (UMC). The brass board of a new control electronics for force sensing, small motor drives, and fiber optic communication has been built and tested (similar to Model B Smart Hand control electronics). The concept design of the slave arm/hand system has been completed, and the system's engineering design is in progress.

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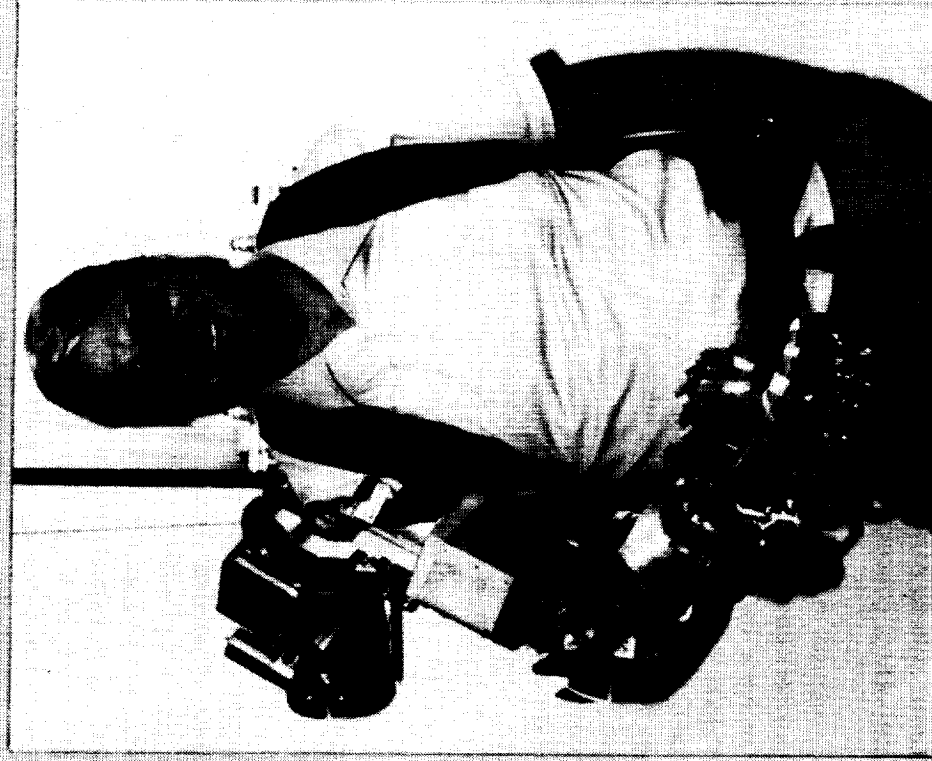
Anthropomorphic Telerobot With Full-Force Reflection

FORCE-REFLECTING 16 DOF 4-FINGER MASTER GLOVE



- ANTHROPOMORPHIC MASTER-SLAVE
TELEMANIPULATOR
 - 7 DOF ARM
 - 16 DOF HAND, 4-FINGERS,
4 DOF EACH FINGER
 - FORCE-REFLECTION AT ALL DOF
- MAN-EQUIVALENT DEXTROUS
MANIPULATION
- NATURAL, HIGH-FIDELITY M/M INTERFACE
- ENABLES EASY REAL-TIME PERFORMANCE
OF COMPLEX, UNSTRUCTURED TASKS

FORCE-REFLECTING 7 DOF MASTER ARM WITH MASTER GLOVE



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Cooperative Dual-Arm Control

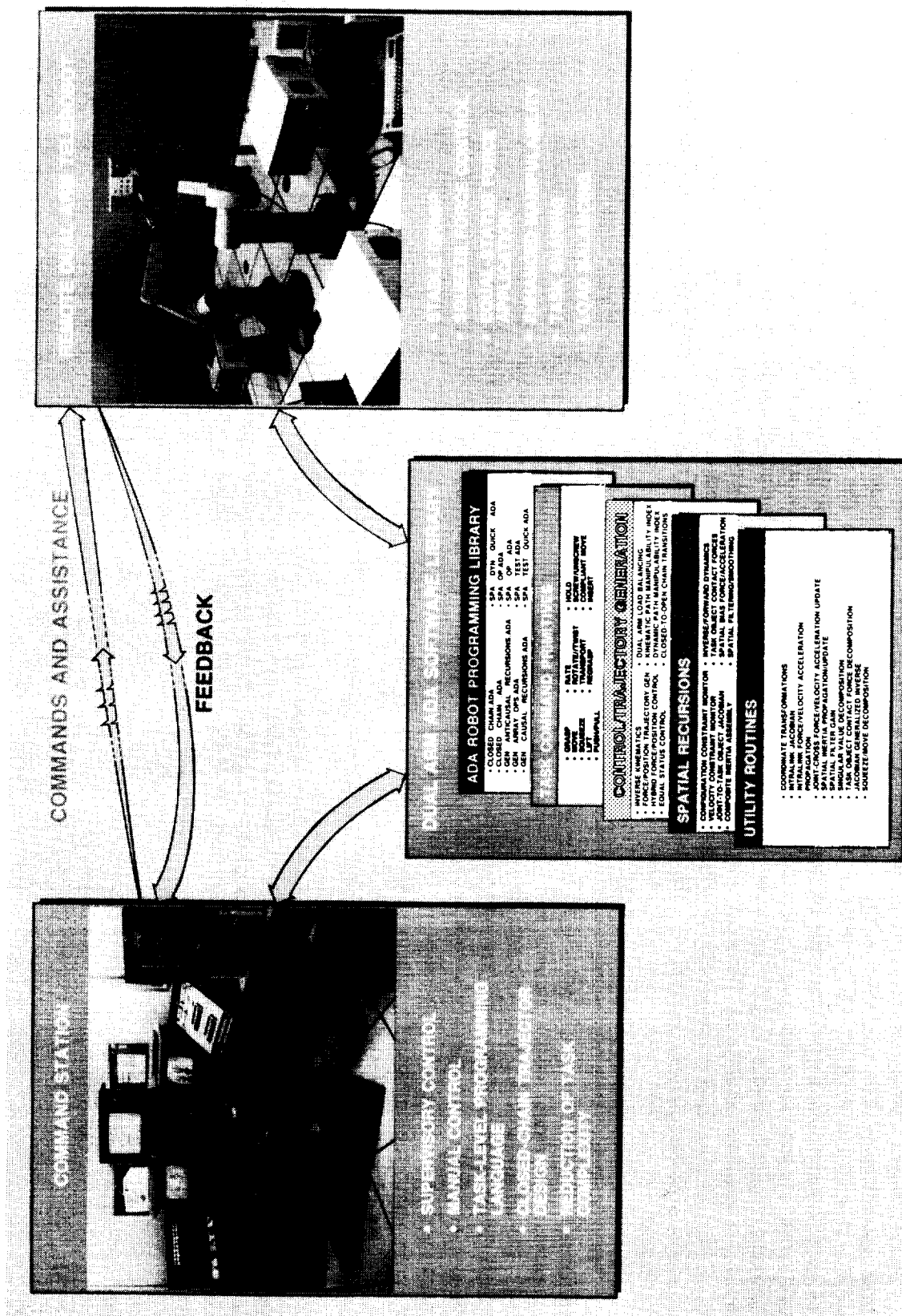
The focus of this research is on task-level CAD-based programming language and a supervised autonomy environment for the operation of equal-status multiarm robotic systems in traded/shared manual and autonomous modes. Numerically efficient and stable spatially recursive trajectory design and hybrid force/position control algorithms for multiarm systems in various stages of contact (sliding, pushing, grasping, etc.) with objects have been studied. Multiarm system computational architectures and flight computer software/hardware requirements have been established. Technology has important concurrent applications to complex single-arm tasks requiring extensive position and force interactions with objects.

Two arms are required to handle heavy, oddly shaped, and/or cumbersome objects. The ability to apply forces at two points and in two directions reduces geometric positioning and force application error by a factor approximately proportional to the length of the object. Up to 10 to 20 times more accurate placement of large objects can result. In performing tasks, a 100-percent increase in operator efficiency over single-arm systems is anticipated. Equal status dual-arms, in which the work done by each arm is allocated during task execution, are a significant improvement over the state-of-art lead-follow systems in which the lead-arm does most of the work. Delicate, fragile, and/or flexible objects can be handled more easily because the internal stress applied to the objects can be precisely monitored and controlled. Supervisory control of multiarm systems compensates for communication time delays of up to several seconds by providing higher level commands to the operator. The dual-arm programming language will allow complex dual-arm operations to be set up and performed more quickly with a minimum of replanning. Setup and calibration of dual-arm experiments can be reduced by a factor of approximately 10. By limiting the cognitive effort, number of separate moves, and complexity required of the operator, more complex tasks can be executed than in pure teleoperation, the probability of task execution errors is less, and errors that do occur can be more easily compensated for.

A new method for handling the complex time and space relationships of multiarm robotic systems has been developed. This method, referred to as Spatial Operator Algebra, is as simple to understand and use as high school algebra. Embedded in the algebra are very efficient spatially recursive algorithms to mechanize the necessary robot mathematics computations. Because of the economy of thought that the algebra allows, it leads to a very simple programming language for multiarm system trajectory generation and control. Approximately 25 high-level Ada language packages (made up of hundreds of smaller Ada modules), implementing about 75 percent of the spatial algebra, have been written, debugged, and tested. These result in multiarm path generation and control algorithms to support dual-arm activities in which the task complexity and computations are transparent to the user. The software is arranged in an open, hierarchical and modular architecture that allows the user, interactively at execution time, to synthesize higher level (e.g. grasp) functions from simpler modules. The current capability has been used to test, by simulation, the internal force control of dual-arm tool/object handling. When completed, the algebra will support development and testing of internal and external force planning and control algorithms, stable grasp operations, load balancing, fragile object manipulation, and enhanced resolution of applied forces. First generation software implementing the spatial algebra will be available to general users from COSMIC in the near future.

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Cooperative Dual-Arm Control



Graphics and TV Perception Systems

Two subtasks, "Graphics Perception Systems" and "Human (TV) Perception Systems," make up this task. The work is focused on three major topics. The first topic is the development of high-fidelity two-dimensional and three-dimensional graphics images of telerobot and work environment for stand-alone use or overlay onto TV images. The second topic is the development of a multiunit (up to five) mono/stereo TV system with microprocessor control of four geometric and three optic variables for each unit, enabling the evaluation of alternative placement, use, and control of camera and lighting resources in telerobot control. The third topic is the development of coordinated use of TV and graphics images in the control station including the placement of displays, the high-fidelity calibration of graphics overlays on TV images, the organization and control of split-screen images, and the formatting and control of status and sensor data displays to provide flexibility and good fidelity in visual perception while reducing operator work load. Together, the objective is to design, develop, and evaluate devices and techniques to improve the operator's visual perception of the telerobot and the workspace.

Telerobotic activities require efficient remote-viewing capabilities for telerobot control, and preview/predictive graphics displays to supplement TV information in control planning and monitoring and to overcome adverse effects of communication time delay in teleoperation. Placement of TV camera and lighting resources defines the attainable visual information envelope for planning and control. Selection and control of camera viewing and optical parameters help reduce operator's disorientation and improve hand-eye coordination in manual control. Arrangement, formatting, and control of TV and graphics monitors in the control station have a fundamental impact on the operator's work load and flexibility in visual perception of task-control details. Preview/predictive computer graphics displays provide solid-shaded or wire-frame polygon images of telerobot and work environment under arbitrary perspective view angles unattainable from TV cameras, which can be supplemented with numbers and text. This capability will reduce operation time (number of move-and-wait steps) under communication time-delay conditions as verified by experiments at MIT, and increase operation safety (planning/monitoring with higher certainty/accuracy), under all conditions.

An IRIS graphics super workstation with stereo display capability has been installed. Solid-shaded and wire-frame graphics images of a dual-arm system (2 Puma 560 robot arms) for stand-alone use or overlay onto TV images have been developed. Complete engineering design of a multi-TV (5 camera) gantry robot for visual resource experiments has been completed. Full frame with one moving unit will be installed in late fiscal year 1989. The final draft of the *Handbook of Human Engineering in Stereoscopic Viewing Devices* has been completed.

Technical Contacts: A. Bejczy, JPL, (818) 354-4568
 D. Diner, JPL, (818) 354-3011
 S. Venema, JPL, (818) 354-1741

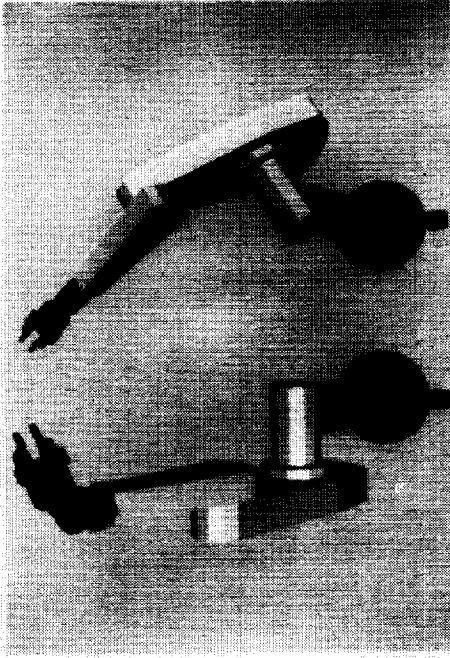
Operator Interface - Graphics and TV Perception Systems

- COMPUTER GRAPHICS EXTENDED TO DUAL-ARM IMAGES AND TO STEREO PERCEPTION
- GANTRY ROBOT MECHANISM DEVELOPED FOR MULTIPLE (FIVE) TV CAMERA VIEWS IN WORK SPACE
- CONTROL AND INFORMATION I/O DEVICES INTEGRATED IN CONTROL STATION FOR DUAL-ARM CONTROL EXPERIMENTS

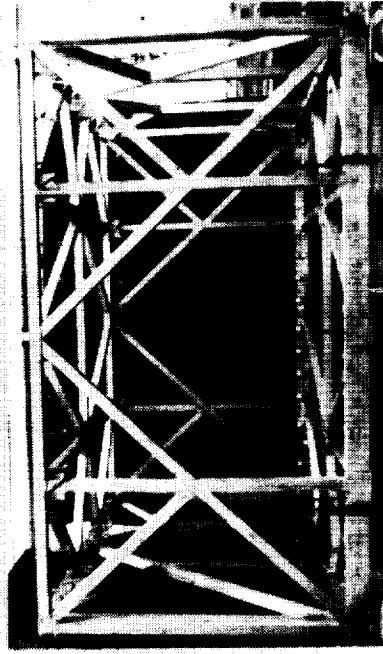
CONTROL STATION



GRAPHICS IMAGE OF DUAL-ARM SYSTEM



GANTRY TV ROBOT FRAME: 17 x 14 x 8 FT



Ground Data System Automation: Spacecraft Health Automated Reasoning Prototype (SHARP)

This task develops and demonstrates multimission automation technologies for unmanned planetary exploration spacecraft and associated ground data systems operations. The initial focus has been on the development of the Spacecraft Health Automated Reasoning Prototype (SHARP) for monitoring of the spacecraft health and status. The SHARP was developed using knowledge-based systems, graphics, object-oriented programming, and other computer science techniques.

Increased levels of autonomy in planetary mission operations are required to meet current and planned NASA requirements in workforce, safety, reliability, and productivity. This task extends the state of the art in application of artificial intelligence technology to accomplish these goals, evaluates the performance in tough operational settings, and transfers the results to NASA user organizations.

The SHARP system was applied to Voyager spacecraft Telecommunications Link Analysis and was to be installed and evaluated as it operated in parallel with actual spaceflight operations during the Voyager spacecraft's encounter with Neptune in August 1989. SHARP automates many manual analysis functions, provides system-wide monitoring and intelligent diagnosis functions, and displays spacecraft status and engineering information to operators using high-resolution interactive color graphics.

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Ground Data System Automation: Spacecraft Health Automated Reasoning Prototype (SHARP)

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Selective Processing in Monitoring: PREMON

This task researches Artificial Intelligence issues in model-based reasoning and planning systems. The purpose of the research is to enable the development of automated-monitoring systems that maximize feedback of critical engineering information from complex, dynamic space systems. Advanced automation is required in such systems because human and computational monitoring resources are very constrained. An approach based on new research in causal modeling, qualitative simulation, and dependency analysis has been developed and prototyped in the PREMON software system.

Future space systems such as Space Station *Freedom*, Earth Observing System, and Mars spacecraft will contain systems with literally thousands of sensors for monitoring and control purposes. Severe computational and human resource limitations preclude exhaustive monitoring and verification of the information on all these channels at all times. Current monitoring technology requires an unacceptable amount of crew time as well as ground operations resources be devoted to monitoring duties.

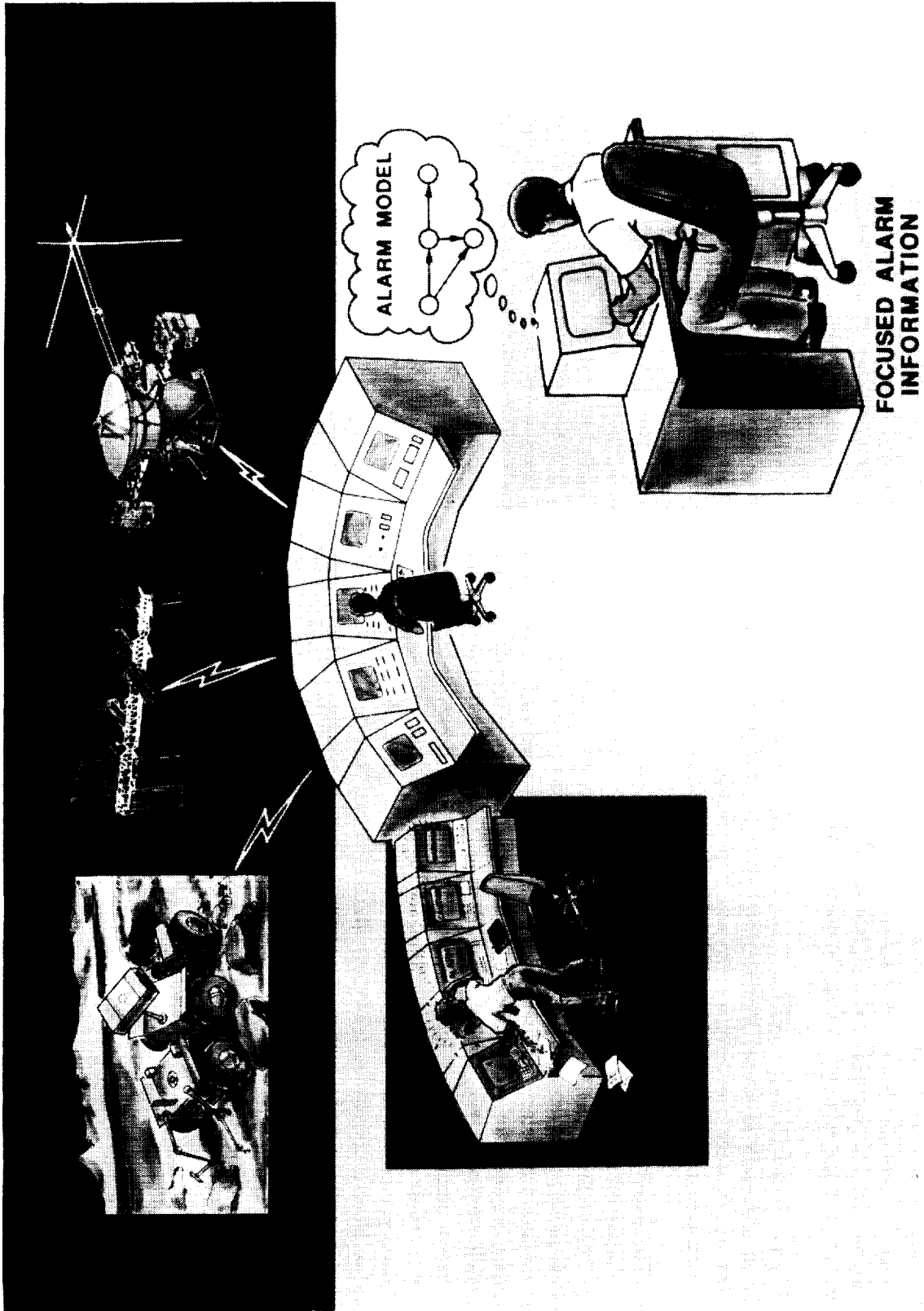
The selective processing approach addresses this problem by exploring research issues in the model-based reasoning and related subfields of Artificial Intelligence in the context of monitoring systems, specifically the focus of attention in real-time inference systems, merging of qualitative and numerical simulation, ambiguity reduction and fidelity maintenance in qualitative simulation, interval reasoning algorithms, and the use of inductive and knowledge-intensive machine learning techniques to support monitoring.

A prototype causal simulator called PREMON was developed as part of research on selective processing and evaluated on a model of the mirror cooling circuit of the JPL 25-ft Space Simulator. The selective processing approach is based on a notion of run-time allocation of monitoring resources such as sensors and computational systems. Resource allocation is automatically planned based on an analysis of causal, teleological, historical, performatory, and design factors in the monitored system. Five research papers were accepted for publication in journals and presented at conferences.

The selective processing approach is being scaled up and extended in the development of a new prototype system. Continued research and evaluation in the thermal control system of the CRAF Mariner Mark II planetary spacecraft is planned.

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Selective Processing in Monitoring



Planetary Rover

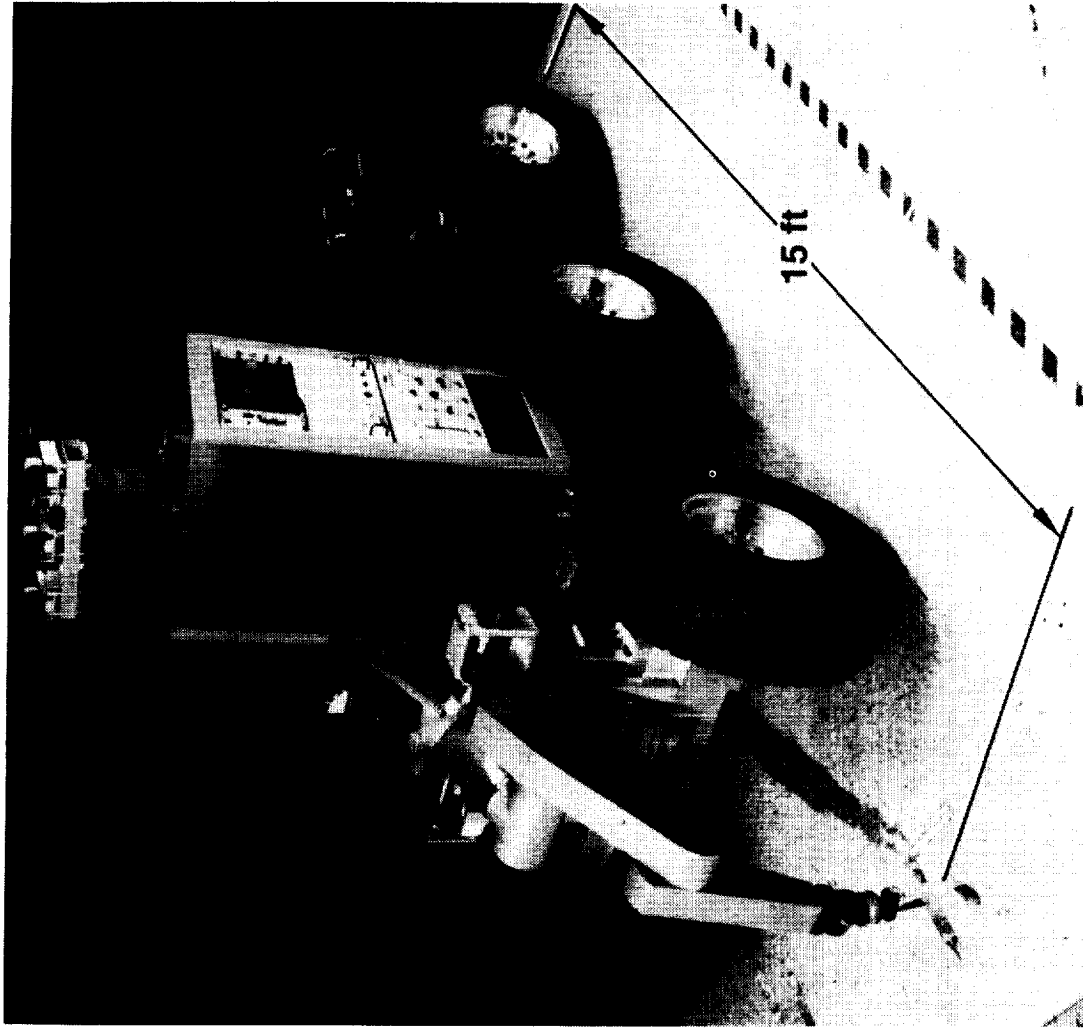
The Pathfinder Planetary Rover (PPR) Program has been initiated to develop, integrate, and validate the required rover technology for enabling robotic and piloted exploration of extensive areas of lunar and planetary surfaces. Because the unmanned missions precede the manned missions, the initial emphasis of the PPR program is on unmanned rover sensing, perception, planning, and execution monitoring technology to enable autonomous navigation through rough, natural terrain.

This program is useful for NASA missions with planetary rover elements, such as exploration and construction support of manned lunar and planetary missions, precursor missions, and unmanned planetary surface exploration missions. Autonomous navigation increases significantly the traverse rate and thus the mission return under conditions of long communication delays for unmanned exploration missions. For manned missions, it offers the potential of freeing the astronauts for more creative tasks.

The fiscal year 1989 PPR program focus has been on the construction of the Rover Navigation Testbed, a six-wheel, three-body, articulated navigation-testbed vehicle ('Robby'). The construction of the testbed is near completion. Pitch and roll articulation between the bodies allows the vehicle to conform to the terrain and provides for enhanced mobility. A commercial robot arm, for future sample acquisition experiments, is mounted on the front body. The middle body contains an electronics rack to house the onboard processors and other electronics, while serving as a mounting pedestal for the stereo camera navigation sensors. The rear body contains a commercial generator and rechargeable batteries. Other work includes the designing and coding of machine vision, path planning, and vehicle-terrain interaction software (initial autonomous navigation testing in natural terrain is scheduled for early fiscal year 1990). A subsystem simulation tool for the future development of autonomous onboard rover and ground-based system executive technology is being developed. Vehicle-terrain analysis tools for future use in mobility design, vehicle dynamics, and control verification and expectation generation are being assessed. The investigation of innovative manufacturing techniques for advanced silicon germanium thermal to electric conversion materials which offer the potential of significant improvement in conversion efficiency and the evaluation of candidate computer and data-storage architectures, hardware and software for a flight rover of a late 1990's vintage and an earthborne testbed in the early 1990's are in progress.

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Planetary Rover Navigation Testbed "ROBBY"



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Telerobotics Testbed

The Telerobot Testbed System will be the first fully integrated laboratory telerobot. It is composed of five major subsystems: Operator Control, Task Planning and Reasoning, Run-Time Control, Manipulation and Control Mechanization, and Sensing and Perception. It is designed to demonstrate system operation in both a purely teleoperated mode and in supervised and cooperative modes where some operations are partially or fully automated. The focus of the fiscal year 1989 testbed activity is two-phased; the focus includes identifying, understanding, and resolving or exploiting the problems and benefits that arise during integration of telerobotics technologies, and calibrating performance during complex task execution under human supervision. The data gathered in both phases will form a primary base for the guidance of future advanced telerobot developments.

NASA is actively considering the on-orbit servicing of space payloads. Doing so purely through EVA may be impractical or inadvisable. NASA is studying the capabilities needed on-orbit to support its missions. Although those studies are still ongoing, it is anticipated that telerobotics will prove to be an essential pillar of that infrastructure, providing many of the same basic services as the EVA crew. This is true only given the existence of, and experience with, the enabling telerobotics technologies. The testbed is a laboratory telerobot system integrating the key technologies in various stages of readiness. This requires deciding how technologies in the NASREM disciplines of sensing and perception, control execution, task planning and reasoning, and operator interface should ideally interact, and then reconciling this to the current state of the art, while providing feedback to the core research efforts to overcome remaining shortcomings. Practice with the integrated system leads to strategies for control over task execution. Hands-on experience also determines the operational support infrastructure needed for mission operations. Where significant technological gaps are identified, the testbed can act as a pathfinder for future major system developments.

All five telerobot subsystems have been delivered to the system integration and test facility. The system has been assembled, and communications among all the subsystems have been established via an Ethernet Local Area Network (LAN) and uniform protocol. Software development is nearly complete; hardware/software integration is proceeding. The selected initial demonstration of system performance involves the use of telerobotics for a simulated orbital servicing task, featuring shared control, traded control, operator designate, and relative update capabilities. All of the software for this demonstration will be in place by the end of fiscal year 1989. Some system performance, with empirical sensitivity to equipment tolerances, has been quantified. Data generated so far indicate, for example, that the automated system operating with the relative update feature can overcome even relatively large errors in the presumed locations of object features. Additional demonstrations are planned in fiscal year 1990.

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Telerobotics Testbed



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Communications

The objective of the Communications Technology Program is to enable data transmission to and from low-Earth orbit, geostationary orbit, and solar and deep space missions. This can be achieved by maintaining an effective, balanced effort in basic, applied, and demonstration prototype communications technology through work in theory, experimentation, and components.

The program consists of three major research and development discipline areas. They are: (1) microwave and millimeter wave tube component research and development; (2) solid-state monolithic integrated circuit research and development; and (3) free space laser communications component and device research and development. The research ranges from basic research in surface physics (the study of mechanisms of surface degradation under high temperature and voltage operating conditions, which impacts cathode-ray tube reliability and lifetime) to generic research on the dynamics of electron beams and circuits (for exploitation in various micrometer and millimeter wave tube devices). Work is also performed on advanced III-V semiconductor materials and devices for use in monolithic integrated analog circuits (used in adaptive, programmable phased arrays for microwave antenna feeds and receivers) on the use of electro-magnetic theory in antennas and on technology necessary for eventual employment of lasers for free space communications for future low Earth, geostationary, and deep space missions requiring high data rates with corresponding directivity and reliability.

Program Manager: Ramon P. De Paula
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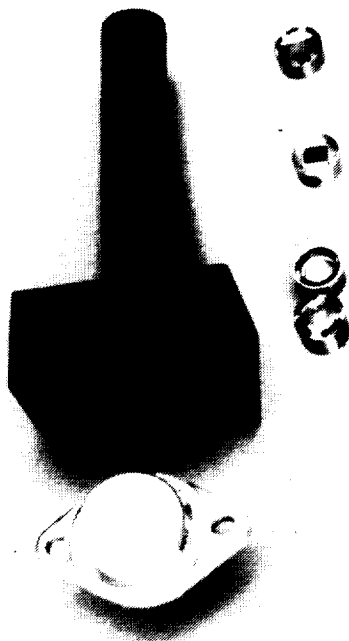
High-Efficiency Lasers

For free-space optical communications and remote sensing, efficient lasers with high-peak output power are required. Continuous-wave laser action was obtained, for the first time, from a thulium-sensitized holmium-doped yttrium lithium fluoride (Tm, Ho:YLF) crystal at room temperature when end-pumped by a pair of diode-laser arrays. Laser output power at 300 K was 26 mW, with a 30-percent slope efficiency and a lasing threshold of 108 mW. A maximum output power of 187 mW was obtained from a 4-mm long crystal at 77 K, resulting in a 67-percent slope efficiency. A compact laser module with no moving parts or optical alignment adjustments and with precisely aligned optical elements has been designed and fabricated; this represents the first known compact Ho-laser module.

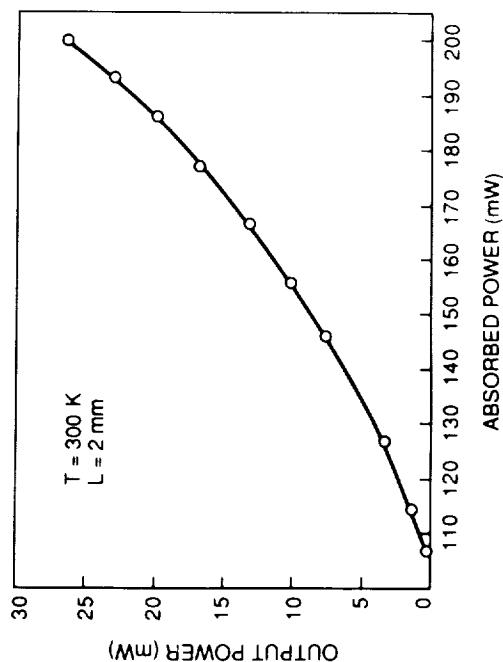
Technical Contact: James R. Lesh, JPL, (818) 354-2766

High-Efficiency Lasers

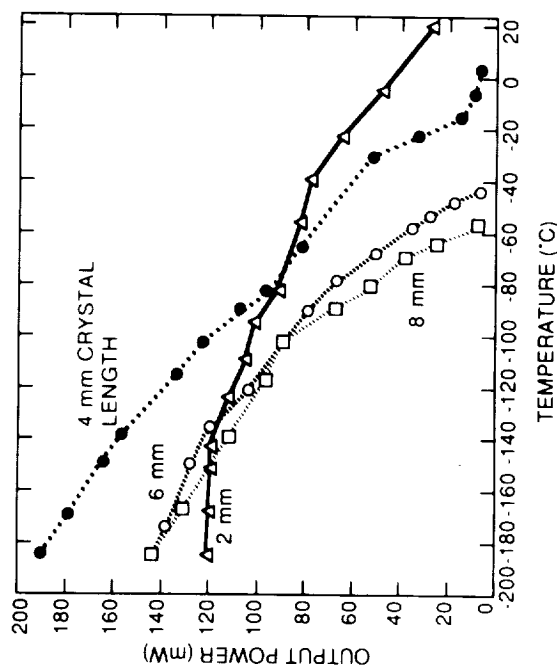
- FIRST ROOM-TEMPERATURE OPERATION OF A DIODE-LASER-PUMPED Tm, Ho:YLF LASER WITH A CUSTOM GROWN CRYSTAL
- OBTAINED 26 mW OF 2 μ m RADIATION AT 300 K AND 187 mW AT 77 K
- DESIGNED AND FABRICATED AN ALIGNMENT-FREE COMPACT LASER MODULE



LASER MODULE BEFORE ASSEMBLY



OUTPUT vs. ABSORBED PUMP POWER



OUTPUT vs. CRYSTAL TEMPERATURE

Space-Optical Communication Laser Development

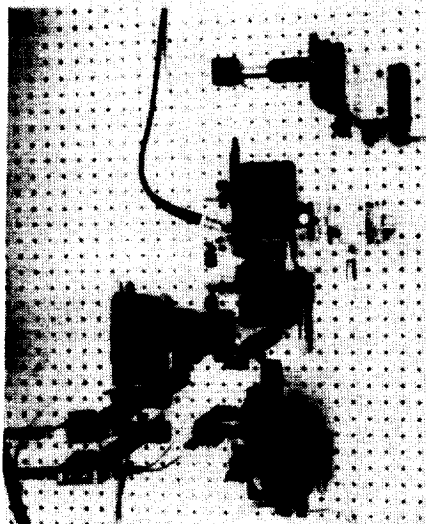
The objective of this research is to develop the technology required for high-power, highly efficient and modulated laser sources for use in free-space optical communications.

A modulated diode-laser-pumped Nd:YAG laser was built using an intracavity acousto-optical Q-switch. Previous research concentrated on operation at low-repetition rates below 10 kHz. This experiment demonstrates reliable operation up to 50 kHz. The laser output power and pulsewidth are strongly dependent on the pulse repetition frequency and the output coupler reflectivity. At a repetition rate of 30 kHz, an output of 80 mW with a pulse width of 30 nsec was obtained when a 95-percent output coupler mirror was used. A detailed theoretical analysis of the Q-switch laser was performed to predict laser output and pulsewidth as a function of the repetition frequency. Experimental and theoretical results of the output power are in close agreement.

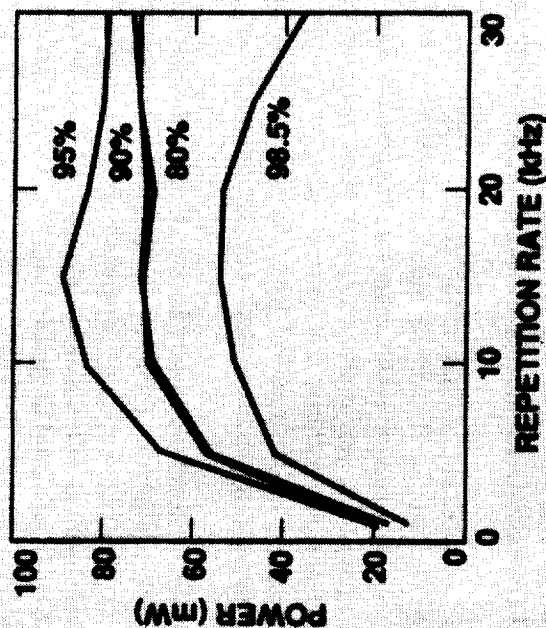
Technical Contact: James R. Lesh, JPL, (818) 354-2766

Space-Optical Communication Laser Development

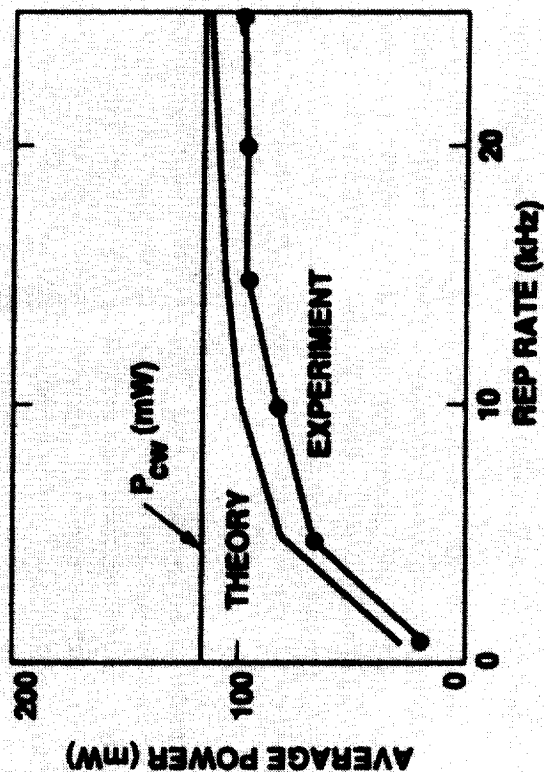
- MODULATED THE OUTPUT OF A DIODE-LASER-PUMPED SOLID-STATE LASER USING AN ACOUSTO-OPTICAL Q-SWITCH
- OBTAINED 90 mW OF 1.06 μm RADIATION WITH 30 nsec PULSEWIDTH AND 30 kHz REPETITION RATE
- COMPLETED DETAILED THEORETICAL ANALYSIS OF THE Q-SWITCHED LASER



EXPERIMENTAL SETUP



PULSE POWER vs REP RATE FOR VARIOUS OUTPUT COUPLER REFLECTIVITIES



AVERAGE POWER vs REP RATE

Reflector Diffraction Synthesis Using Optimization Techniques

Advanced multiple-beam and contour-beam reflector antennas are required for future scientific, communication, and military missions. These antennas must be capable of generating beams with stringent off-axis performance. In particular, the high-gain and low sidelobe radiation characteristics are considered to be viable performance requirements for many applications. Any advances in achieving antenna/feed configurations capable of satisfying the requirements are important steps in realizing the overall mission objectives.

Reflector synthesis results in the design of reflector profiles that are capable of radiating antenna patterns for high-gain, low-sidelobe, multiple-beam and contour-beam applications. In the past, geometrical synthesis procedures were the basis for most of the designs. In these procedures, the reflector profiles are synthesized first, utilizing the phase path and energy constraints, and then a diffraction analysis is performed to ensure that the desired radiation objectives are met. Recently, due to the advent of powerful computers, diffraction synthesis has evolved into a useful approach to achieve demanding performances. In this approach, the reflector shape is determined in conjunction with the diffraction analysis procedure. The advantage of this procedure is that the diffraction effects are automatically incorporated into the course of the synthesis.

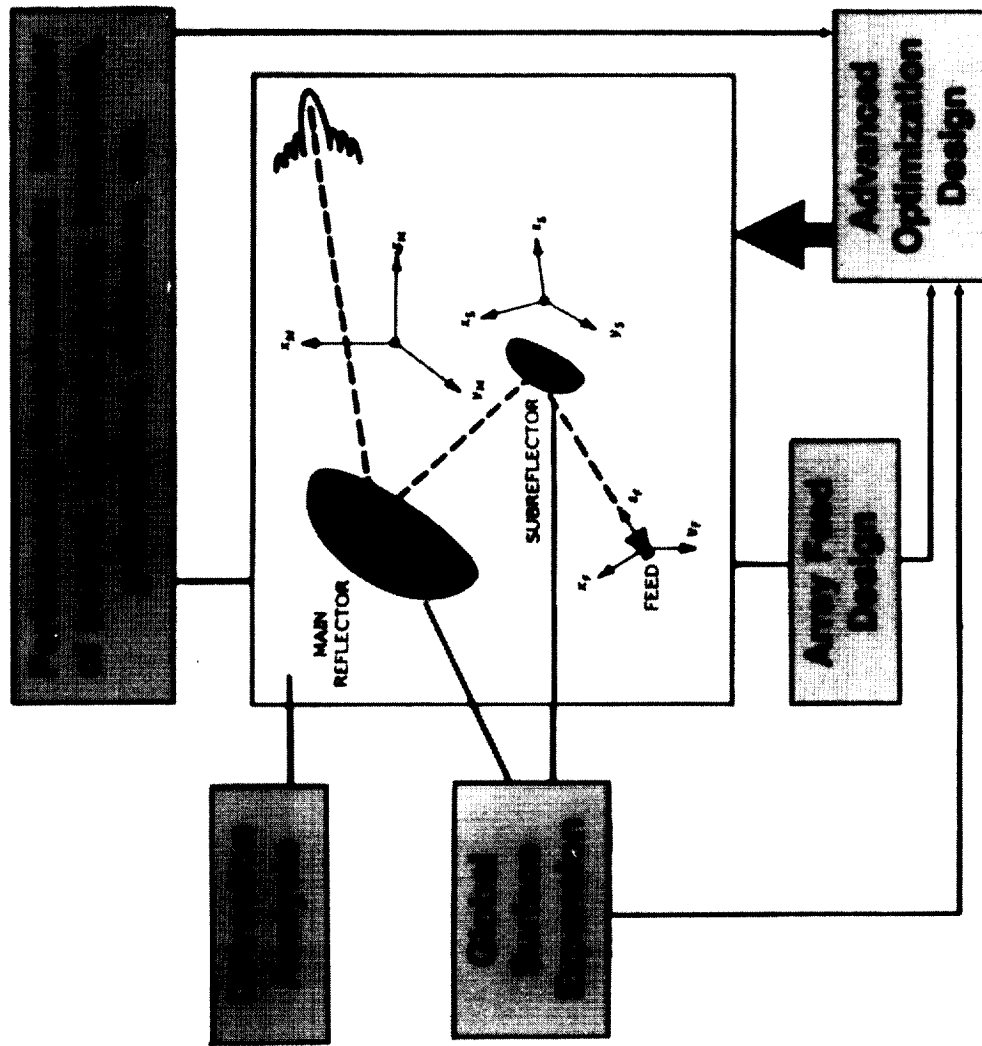
Recently, a novel approach based on the utilization of global expansion functions using Fourier-Jacobi expansion has been developed which allows the reflector surface diffraction synthesis. The method can be applied to both single and multiple reflector configurations. The key step is to expand the reflector surface in terms of global expansion coefficients and then utilize an optimization algorithm to determine the unknown surface coefficients by imposing required performance objectives on the radiated far field. In the course of the optimization procedure, the far-field pattern at specified observation angles is determined using diffraction analysis formulations.

The steps used in this diffraction synthesis are depicted in the figure. For optimization purposes, the Levenberg-Marquart algorithm is used. This optimization obtains the solution of nonlinear least-squares problems by minimization with respect to coefficient vector for the sum of squares of residuals of a prespecified performance requirement. So far the algorithm has been tested by designing reflector surfaces capable of producing beams which are scanned away from the reflector axis. Additional refinement of the technique is being investigated for multiple reflector configurations and low sidelobe radiation patterns.

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Reflector Diffraction Synthesis Using Optimization Techniques

- **Advanced multiple beam and contour beam reflector antennas are required for future scientific, communication and military missions.**
- **Diffraction synthesis provides the ultimate design tool for reflector shaping.**
- **Optimization technique results in the best design to satisfy demanding performance characteristics.**



Cassini Flight Experiment Definition

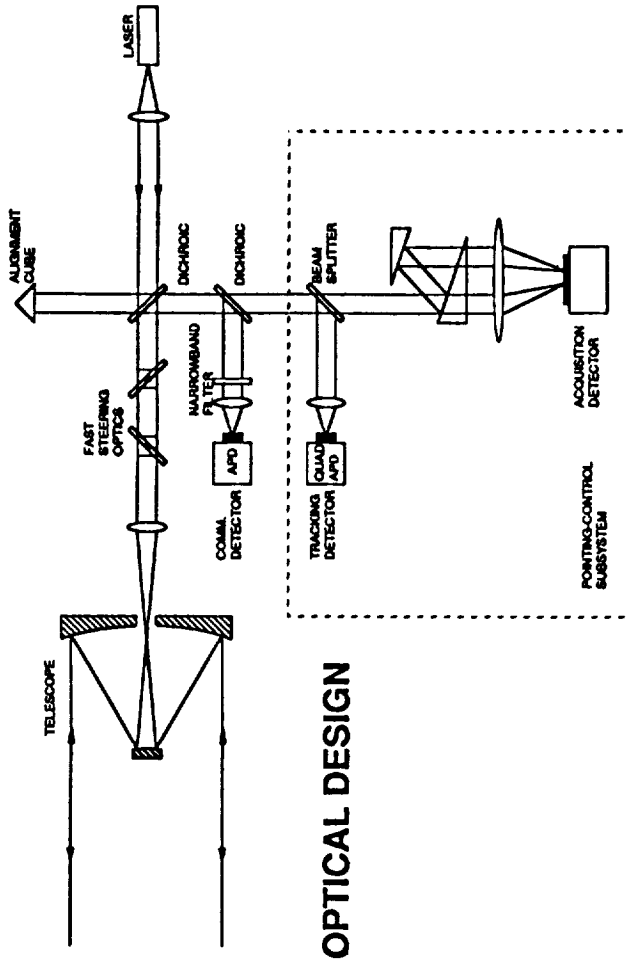
The long-term objective of this work unit is the detailed design, development, fabrication, and testing of an engineering model for a deep-space optical communications experiment package. The objective of the first year is to complete a multidivisional preliminary design study in order to evaluate mass/performance and power/performance trade-offs, to identify critical technologies requiring development, and to plan subsequent activities.

The generic requirements for the initial study come from a hypothetical experiment package for Cassini. The study will be applicable, however, to flight engineering tests and possible mission enhancements for a number of other missions under consideration by NASA. These include the multiasteroid flyby and orbiter and the Uranus/Neptune orbiter/probe. Early results have identified two critical issues: laser power efficiency and spatial tracking in the presence of scattered sunlight. Plans for resolving these are being suggested as part of the study and will be investigated as part of future activities.

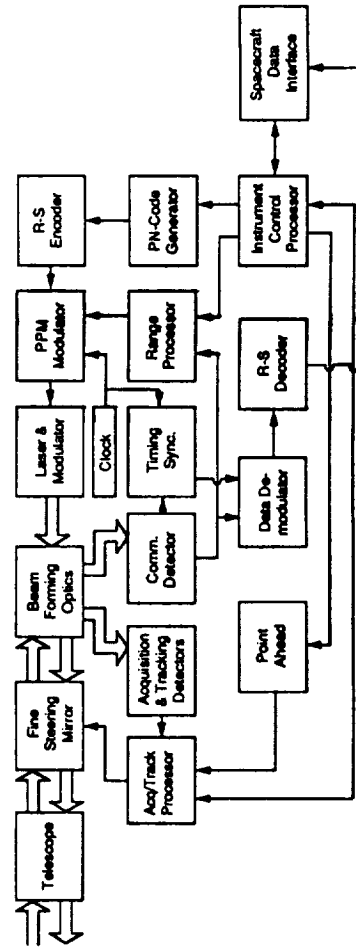
Technical Contact: James R. Lesh, JPL, (818) 354-2766

Cassini Flight Experiment Definition

- FORMED MULTI-DISCIPLINARY STUDY TEAM
- ISSUED STUDY GUIDELINES AND PRELIMINARY HARDWARE ARCHITECTURES
- LASER AND TRANSCIEVER ELECTRONICS STUDIES NEAR COMPLETION
- LASER EFFICIENCY AND STRAY SUNLIGHT IDENTIFIED AS CRITICAL ISSUES



Functional Block Diagram



- BASIC TEST PACKAGE DESIGNED FOR 30 KBPS FROM 3.5 AU
- IMPACT OF INCREASED DATA RATE PERFORMANCE AND INCREASED RANGE BEING ASSESSED

Integrated Optical Communication Test Bench

The integrated optical communication test bench (IOCTB) has been designed to provide a test facility for the detailed evaluation of performance, and for the design constraints of optical communication technology subsystems such as laser transmitters, modulators, tracking detectors, and high-gain data detectors in a realistic operational environment. The immediate task is to use the test bench to develop and test software algorithms that simulate the acquisition and tracking of a point-source target (a realistic representation of a distant tracking beacon).

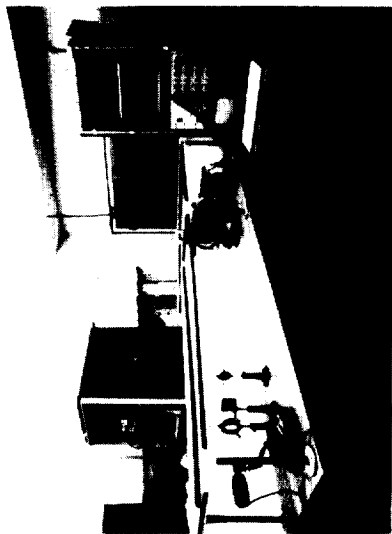
The test bench will also be used to investigate the effects of various tracking noise sources such as simulated host-spacecraft vibrations, and background noise such as would occur when tracking close to the Sun. Recent accomplishments include the formulation of a theoretical control-loop model of the acquisition process, and the testbed verification of a developed acquisition and tracking algorithm.

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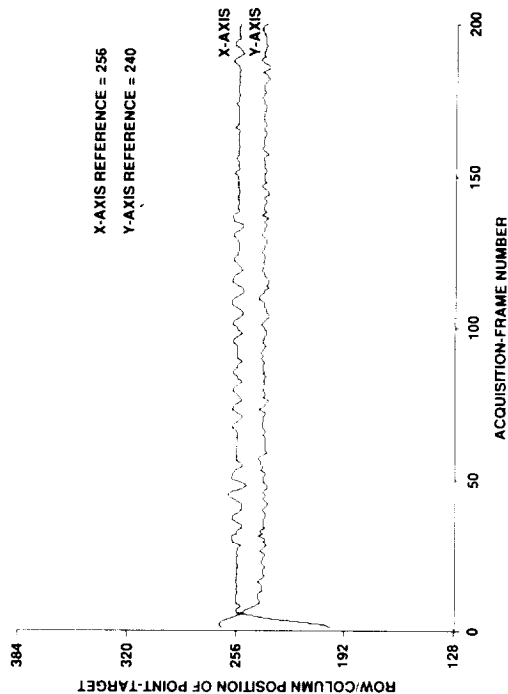
Integrated Optical Communication Test Bench

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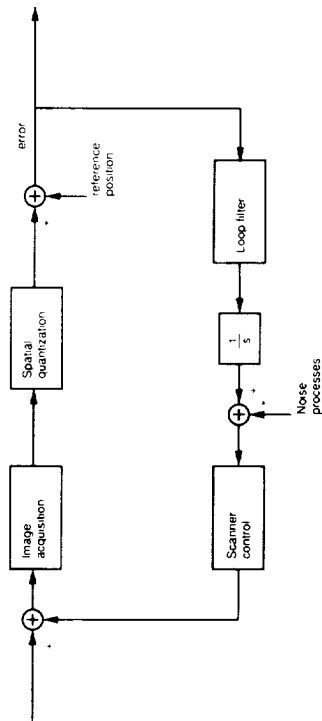
- ANALYZED PERFORMANCE OF SUB-PIXEL ACCURACY TRACKING ESTIMATORS FOR EXTENDED BEACONS
- COMPLETED ACQUISITION AND TRACKING LOOP ANALYSIS FOR A POINT-SOURCE BEACON
- POINT-SOURCE ACQUISITION AND TRACKING ALGORITHM DEVELOPED AND TESTED



TEST BENCH SIMULATOR



ACQUISITION DETECTOR RESPONSE



THEORETICAL CONTROL LOOP MODEL

High-Speed GaAs MESFET Optical Controller

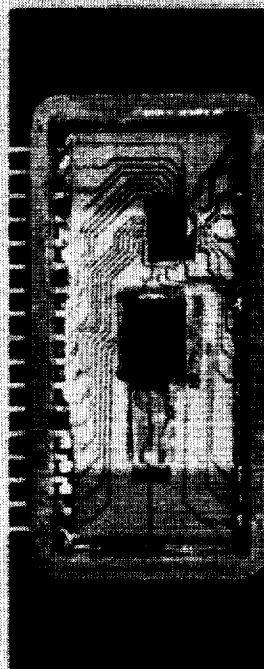
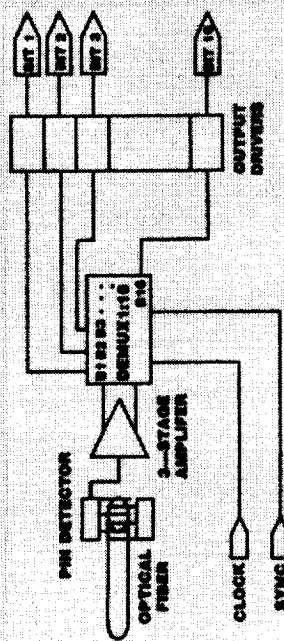
One of the difficulties in the implementation of phased-array antenna structures for communications, radar, or sensing applications is the complexity of the feed and control interconnections. One possible approach to solving these problems is through the use of optical fibers for transmission of control signals and rf signals throughout the array. The use of optical fiber has the potential to reduce size, weight, and mechanical complexity, to allow transmission of higher data rates, and to reduce cross talk and electromagnetic interference.

Over the last three years, LeRC has developed a GaAs chip capable of providing the interface between an optical fiber, carrying up to 1 Gbps of control data, and a monolithic microwave IC. The chip utilizes technology such that it may be integrated directly with the MMIC if necessary. In the last year, a number of chips have been delivered, and subsystem test and evaluation have been initiated. Specifically, transmission and demultiplexing of high-speed data have been demonstrated, as has control of an MMIC 32 GHz phase-shifter. Demonstration of optical control of a small array is planned.

Technical Contact: Kul Bhasin, LeRC, (216) 433-3767

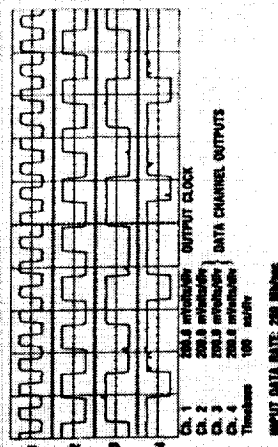
High-Speed GaAs MESFET Optical Controller

- APPLICATIONS:**
- PHASED ARRAY ANTENNAS
 - HIGH SPEED COMPUTER INTERCONNECTS
 - LOW POWER RECEIVER ARRAYS
 - NEURAL NETWORKS



CHARACTERISTICS:

- INPUT DATA RATE ~ 300 MBIT/S
- PROVIDES 16 PARALLEL OUTPUTS FOR SINGLE SERIAL INPUT
- INPUT OPTICAL POWER < 200 μ m
- GaAs E/D MODE MESFET TECHNOLOGY
- LOW ELECTRICAL POWER CONSUMPTION ~ 277 mW



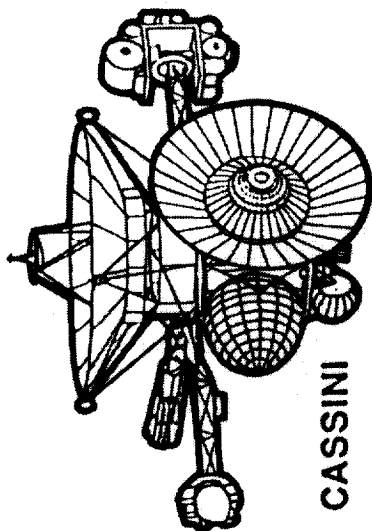
32-GHz GaAs MMIC Phase-Shifters

Monolithic phase-shifters are a critical component for any millimeter wave system utilizing a phased-array antenna. In particular, Ka-band phased-array antennas have been discussed as a candidate for use on several deep-space communications links. The Ka-band phased-array system has several advantages over the presently used communications link. These advantages include rapid acquisition and tracking through electronic beam steering, minimum antenna package volume, reduced deployment complexity, and improved link margin and/or enhanced data rates.

During the last year, LeRC has managed the development of a new phase-shifter design at Honeywell in Minneapolis. The new chip, in addition to being significantly smaller than previous versions, utilizes both switched and loaded line techniques in order to achieve the required four bits of phase-shift. The module has exhibited 1.5 dB of insertion loss per bit, with a variation in insertion loss of only plus/minus 0.75 dB as the phase state is varied. Chips have been supplied to JPL in support of an ongoing breadboard program aimed at the evaluation of various Ka-band phased array concepts.

Technical Contact: Regis F. Leonard, LeRC, (216) 433-3500

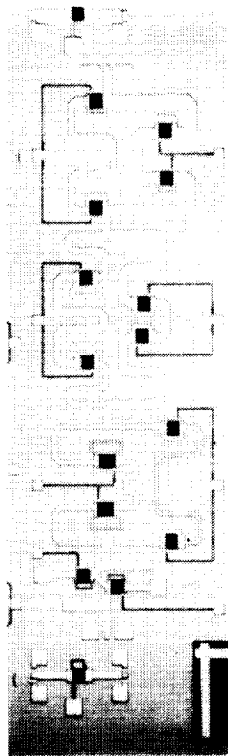
32-GHz GaAs MMIC Phase - Shifters



CASSINI

DEEP-SPACE PHASED ARRAYS
FOR TELECOMMUNICATIONS

FOUR-BIT SWITCHED LINE/LOAD LINE ϕ SHIFTER



CHIP SIZE: 5.5 mm \times 1.9 mm

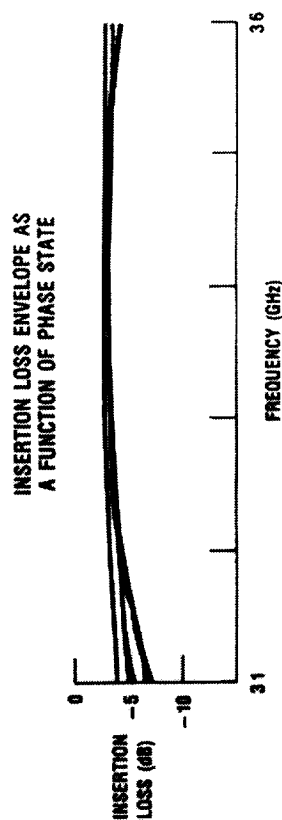
MAJOR PERFORMANCE GOALS

FREQUENCY RANGE: 31.0 TO 33.0 GHz

INSERTION LOSS: < 2.0 dB/bit*

INSERTION LOSS ENVELOPE: $\leq \pm 1.5$ dB*
NUMBER OF BITS: 4(180°, 90°, 45°, 22.5°)

*ACHIEVED -6 ± 0.75 dB LOSS FOR FOUR
BIT PHASE SHIFTER AT 34-36 GHz



Coplanar Waveguide Development

Designers have utilized microstrip technology almost exclusively in the development of microwave monolithic integrated circuits. The disadvantages of microstrip transmission lines are that they become lossy at millimeter wave frequencies, they frequently require VIA holes in the implementation of specific circuitry, and they are often difficult to integrate with other MIC components.

Coplanar waveguide (CPW), however, which includes the ground plane on the top surface, avoids most of these difficulties. Specifically, implementation of millimeter wave integrated circuits in CPW will offer advantages such as higher levels of integration, elimination of VIA holes, lower loss circuits, compatibility with other MIC techniques, all surface-mount integration, and suitability for on-wafer testing. Taken together, these advantages will yield higher performances and lower costs for millimeter wave circuits.

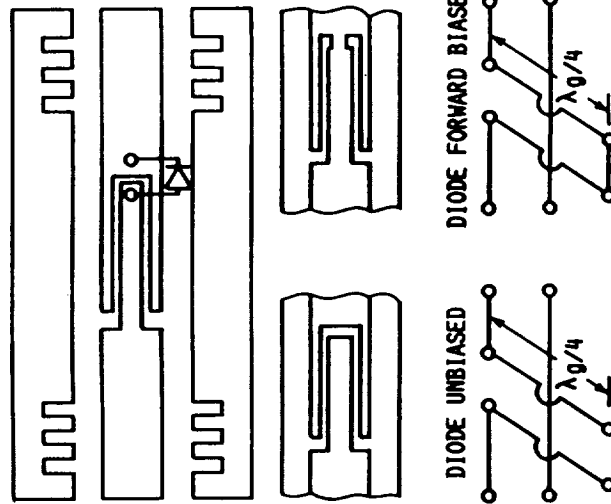
LeRC is engaged in a program to design, fabricate, and model, in CPW, a number of components appropriate for space communications or radar systems. Two of these, a COAX-to-CPW power divider and a pin-diode switch, have been demonstrated. Other components at higher frequencies are being designed. The result of this work will be the generation of some of the models and other data required before CPW can be utilized in a CAD environment.

Technical Contacts: George E. Ponchak, LeRC, (216) 433-3504
Ranee N. Simons, LeRC, (216) 433-3462

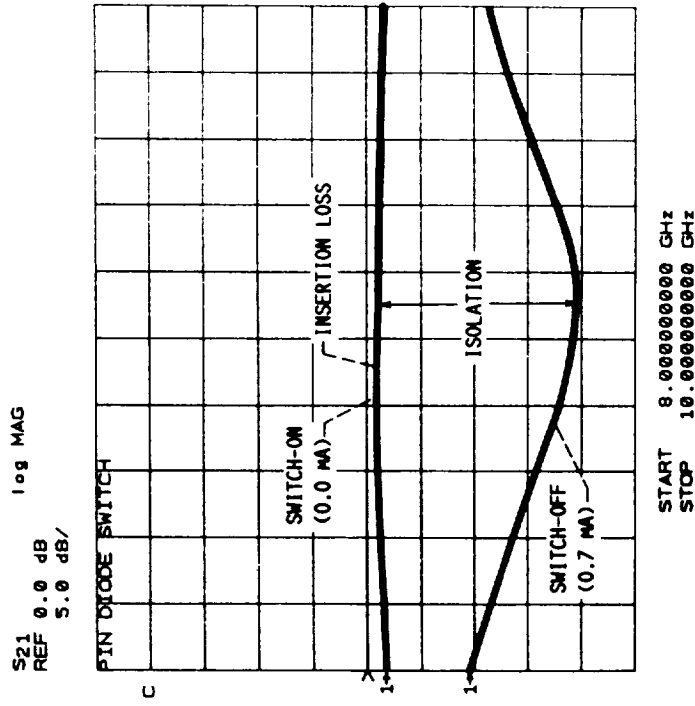
CPW Pin-Diode Switch

- NARROWBAND
- HIGH ISOLATION
- SUITABLE FOR MILLIMETER-WAVE CIRCUITS

CPW P-I-N DIODE SWITCHED-SERIES-STUB SWITCH CHARACTERISTICS



SWITCHED-SERIES-STUB SWITCH CHARACTERISTICS



Phase-Adjusted Taper for Increasing Efficiency in Coupled-Cavity Traveling Wave Tubes

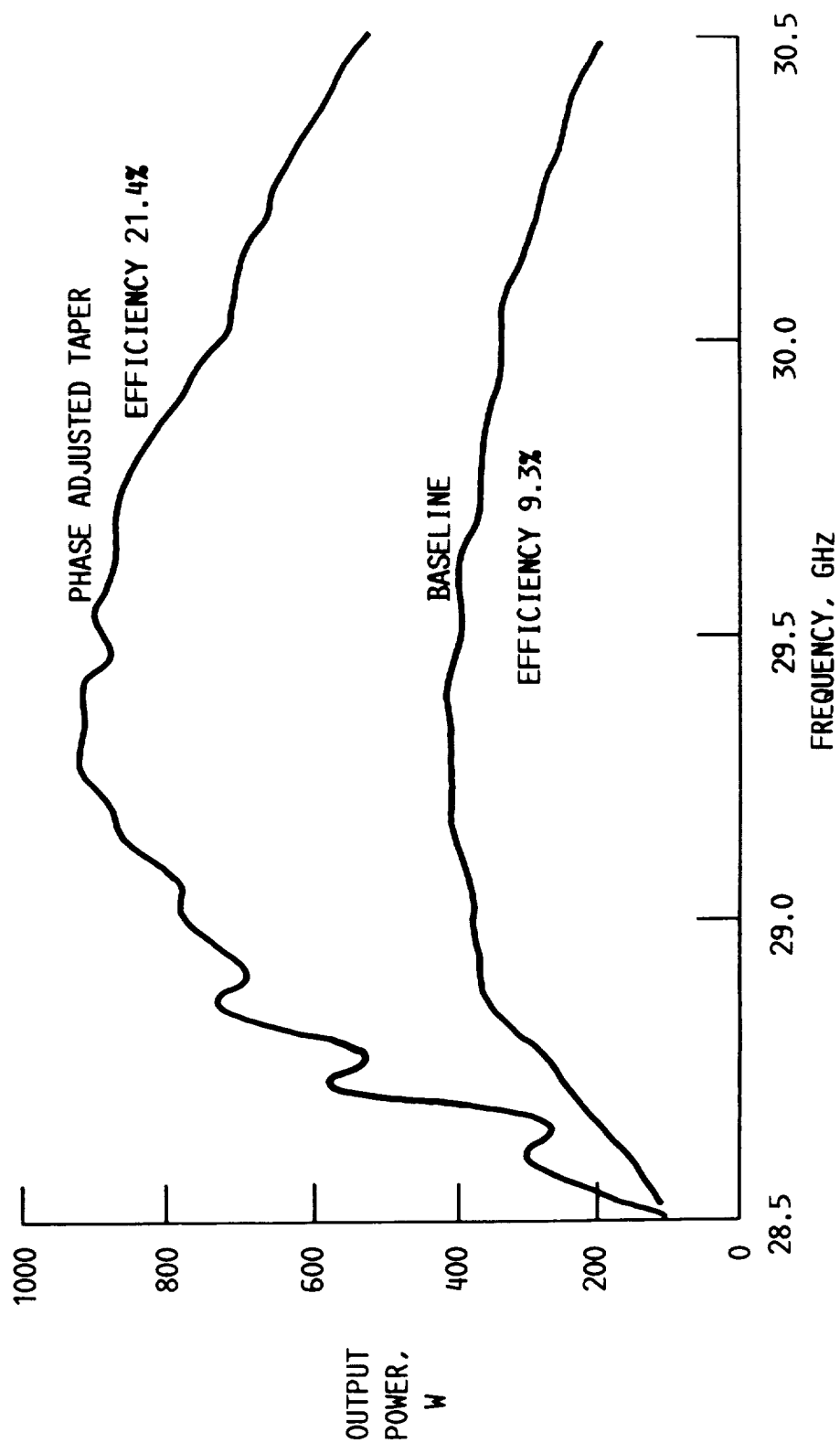
Testing began on the fourth Ka-band coupled-cavity Traveling Wave Tube (TWT) built under research and development contract NAS3-24899, "Study of Methods for the Reduction of Distortion in High Power TWT's," with Hughes Aircraft Company. This TWT is the first to employ a phase-adjusted taper (PAT), which was recently developed by J. Wilson, to increase efficiency in coupled-cavity TWT's. The first three tubes built on this contract successfully demonstrated the lowest small-signal-gain ripple ever reported for millimeter wave-coupled cavity TWT's.

In the PAT, the phase between the rf wave and the electron bunch is adjusted for optimal energy extraction from the beam. The LeRC coupled-cavity TWT computer code has been programmed to automatically generate the cavity lengths needed to maintain the desired phase relationship.

Experimental output power is shown in the figure for the PAT TWT, which is presently being operated at low duty cycle and reduced beam current, and the baseline TWT. The PAT increases peak output power from 410 W to 920 W. The rf efficiency is increased by a factor of 2.4 from 9.0 percent to 21.4 percent.

Technical Contact: J. Wilson, LeRC, (216) 433-3513

Coupled-Cavity Traveling Wave Tube With Phase-Adjusted Taper



Miniature Traveling Wave Tube

The purpose of this effort is to employ modern microfabrication techniques and computational procedures to develop a new class of very small millimeter wave Traveling Wave Tube (TWT)'s. These tubes will be designed to produce rf output powers of approximately 1 W with good efficiency. Typically, when low-power tubes are built, they are inefficient versions of high-power tubes and are similar in size.

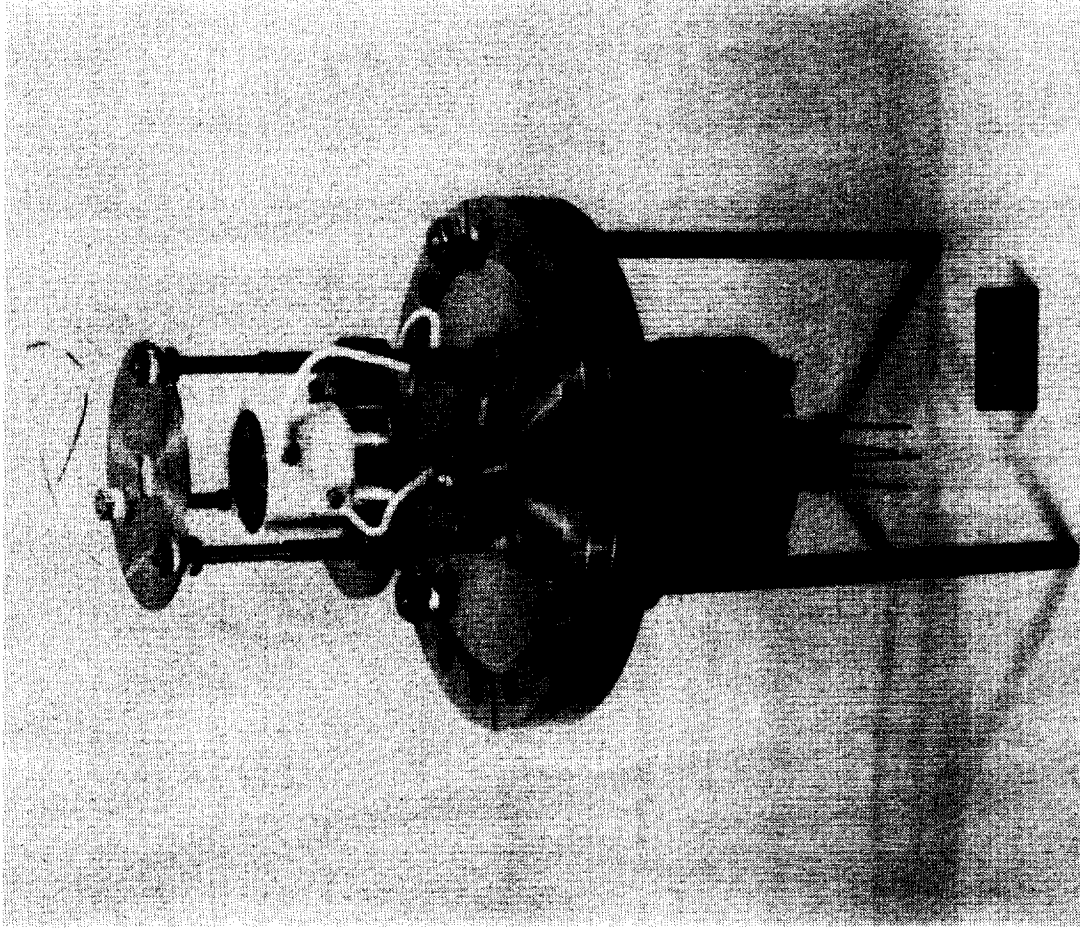
A trapezoidal vane slow wave structure was chosen for a 30-GHz miniature tube, and fabrication will commence shortly. The input and output couplers for this tube are still being modified and tested to reduce losses.

The electron-beam gun for the miniature tube, which has been constructed and is awaiting testing, is shown in the figure. The installation of a new and improved Faraday cup on the beam-testing apparatus and the failure of one of three step indexers are delaying the test. Extensive software for controlling the step indexers and digital oscilloscope for the electron beam-testing apparatus has been written. A program for scanning and measuring the electron beam cross-section characteristics will be used for the test.

The vacuum system for the testing of the completed miniature TWT is being constructed.

Technical Contact: T. Wallett, LeRC, (216) 433-3673

Miniature Traveling Wave Tube - Electron Gun



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High-Efficiency Traveling Wave-Tube Amplifiers for Deep-Space Communications

The Traveling Wave Tube (TWT) efficiency enhancement program at LeRC is providing the technology needed for high-efficiency millimeter wave communications amplifiers for future NASA missions in deep space.

The TWT shown in the figure is a 20 W X-band TWT with a high-efficiency slow wave circuit designed by LeRC personnel and fabricated by Watkins-Johnson. The circuit developed for this TWT was adopted for use on the TWT that will be flown on the Mars Observer, and will exceed mission requirements for efficiency.

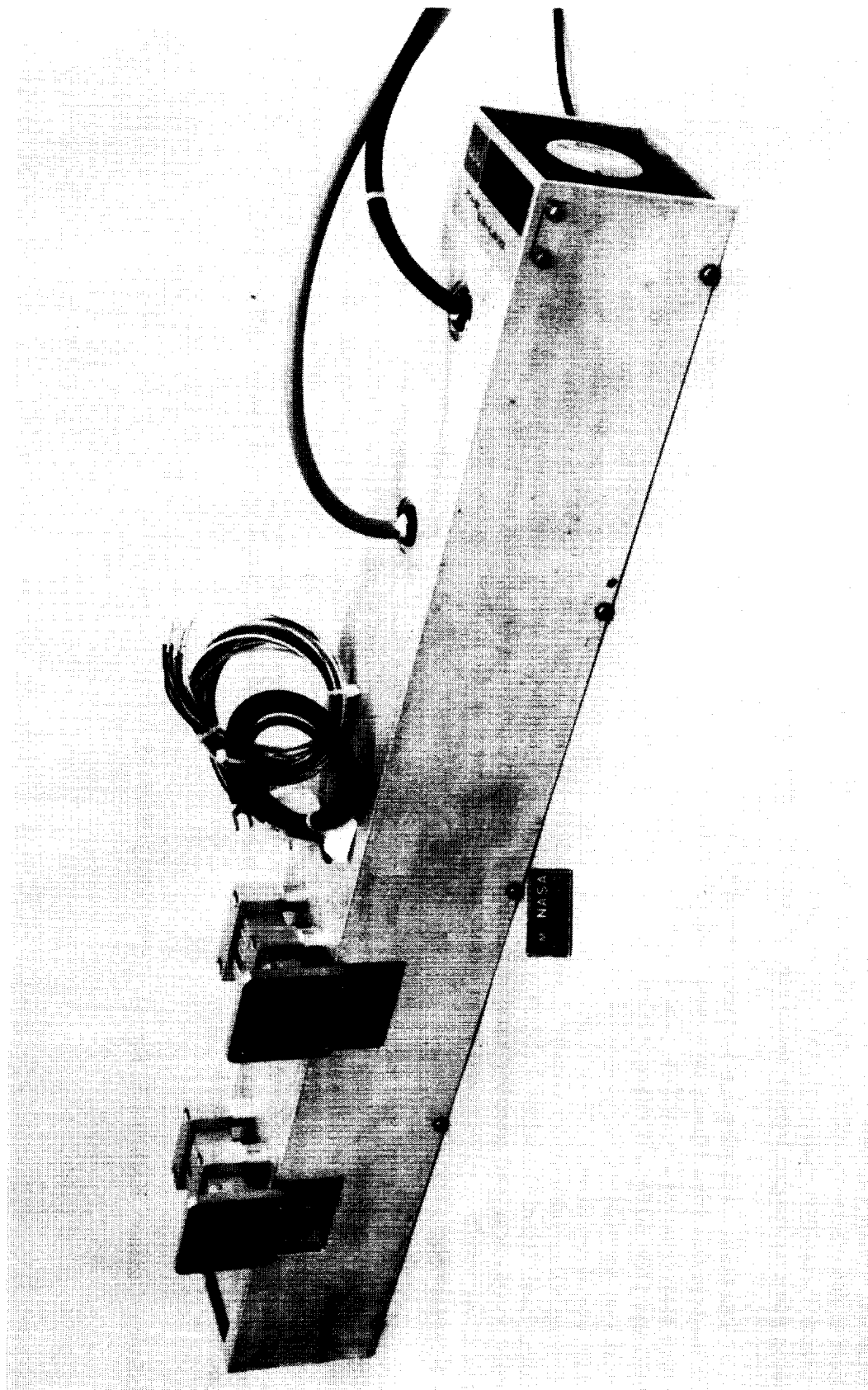
Efficiency enhancement technologies apply throughout the TWT and include improving the interaction between the electron beam and the electromagnetic wave, recovering the energy in the spent electron beam, improving electron beam transmission, reducing cathode heater power, and reducing secondary electron emission from collector electrodes. The work involves both computer-aided design and analysis as well as experimental verification.

The next objective of this program is to produce a very efficient 32-GHz TWTA which produces 7 W of rf output power with DC power input to the power supply of only 20 W. Achieving this goal would approximately double the efficiency of 30 GHz TWTA's now available at this power level. The program objectives were chosen after consultation with JPL about possible application to the Cassini Mission.

The TWT incorporates an advanced helix interaction section (dynamic velocity taper) design and a high-efficiency multistage depressed collector, as well as a spent beam refocusing section.

Technical Contact: A. N. Curren, LeRC, (216) 433-3519

High-Efficiency Traveling Wave-Tube Amplifiers for Deep Space



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Free-Space Laser Communications Transmitters and Receivers

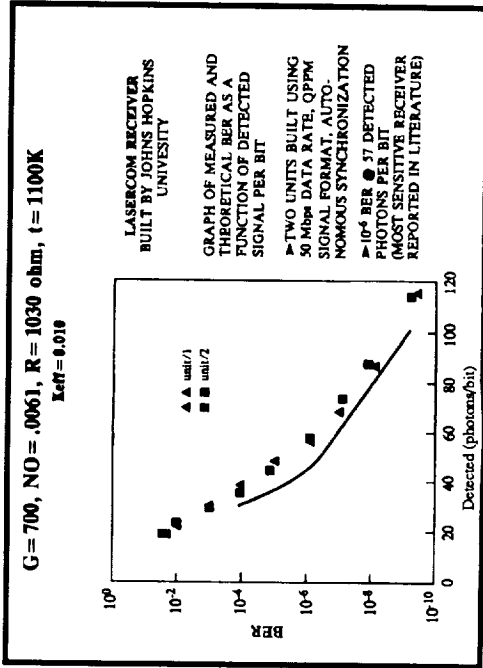
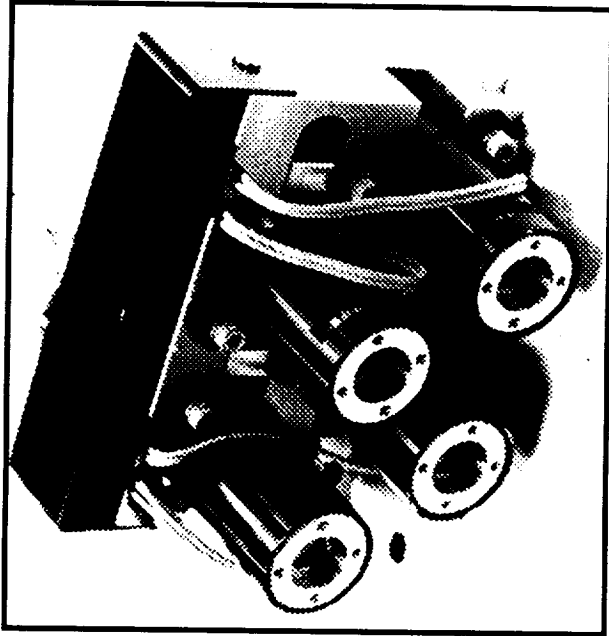
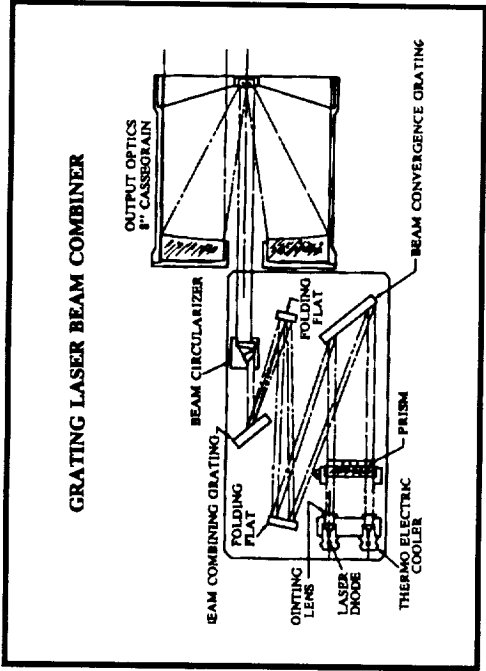
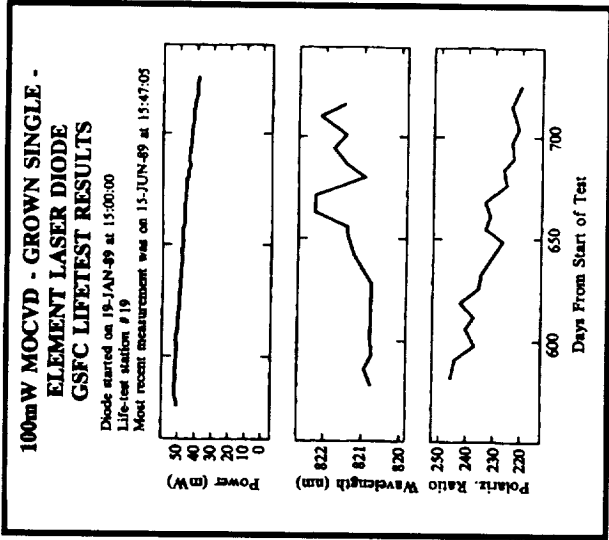
AlGaAs laser-based systems are attractive candidates for free-space optical communications between satellites because of their small size and weight, and their high efficiencies. They are capable of data rates up to several Gbps under direct injection current modulation. Until recently, the best of such lasers was limited to peak powers of 70 mW, and to cw powers of 35 mW; NASA's projected data rates are on the order of several hundred Mbps and this, coupled with bit error rates of less than 10^{-6} , imposes a minimum transmitter power requirement of 100 mW. In addition, stable single spectral and spatial mode operation is required over mission lifetimes ranging from a few to tens of thousands of hours.

The GSFC is developing the high-power AlGaAs laser-based transmitters to meet these requirements. Significant progress has been made in this area. During fiscal year 1989, 100 mW, MOCVD-grown single element AlGaAs lasers with single mode far-fields and spectra have come on the market. These have been evaluated and are now under lifetest at the GSFC. Lifetest data obtained at the GSFC and TRW on 35 mW lasers developed for the DDLT laser transceiver indicate that at 35 mW average power, 70 mW peak, mission lifetimes on the order of 20,000 hours at room temperature are possible. Injection-locked high-power AlGaAs diode-laser phase-locked arrays have demonstrated 250 mW peak power in a nearly diffraction-limited single lobe at 50 Mbps. Hybrid current drivers capable of driving either positive- or negative-polarity laser diodes at 200 Mbps and up to 150 mW output have been incorporated into the Grating Laser Beam Combiner II (GLBC). Code E will fund future hybrid driver development starting in fiscal year 1990. The GLBC II optical, mechanical, and electrical subsystems are complete and ready for integration and testing. An analysis of the thermally induced stresses and resultant defocus and beam misalignment is under way. Code T will sponsor future development of the GLBC starting in fiscal year 1990.

High-sensitivity photodetectors significantly enhance optical communications systems performance, allowing high data rates and lower transmitter powers. Work in this area at the GSFC has developed silicon avalanche photodiode (Si APD) receivers with the highest sensitivity yet reported at medium (50 Mbps) and high (300 Mbps) data rates. Accomplishments during fiscal year 1989 include Si APD receivers (two units built) with slot and frame synchronization that demonstrated 10^{-6} BER at 57 photons per bit, 50 Mbps. In addition, AlGaAs staircase APD development at ATT-Bell focused on optimizing performance of 10-stage devices. These devices demonstrated gains greater than 800 with spatial gain uniformity of better than 1 percent over its active area ($1.3 \times 10^{-4} \text{ cm}^2$), and demonstrated 5 GHz bandwidth.

Technical Contact: Kathrine A. Forrest, GSFC, (301) 286-7138

Free-Space Laser Communications Transmitters and Receivers



Computer Sciences

The overall goal of the Computer Sciences Research Program is to foster the advancement of computing technology targeted at aerospace applications. This goal is being realized through a program of basic research and experimentation that focuses on developing core skills within the Agency in disciplines critical to NASA and on maintaining a strong university base of fundamental research in aerospace computer science.

The research program is improving the state of knowledge of fundamental aerospace computing principles and advancing computing technology in crucial space applications, such as software engineering for very reliable systems and information extraction from data collected by scientific instruments in space.

This program includes the development of special algorithms and techniques to exploit the computing power provided by high-performance parallel processors and special-purpose architectures. Problem areas of importance include computational fluid dynamics, computational chemistry, structural analysis, signal processing, and image processing. The computer architectures of interest include common and local memory multiprocessors, single-instruction stream/multiple data stream processors, static data flow processors, systolic arrays, and heterogeneous multiprocessors with custom processors. Research is conducted in programming languages and environments, parallel and distributed operating systems, and performance measurements.

Research is also being conducted in the fundamentals of data base logic. This work has resulted in the development of a common user interface for accessing data from several data bases even when the data bases being accessed have very different structures. This work provides the foundation that will enable NASA space data users access to multiple data bases independent of the data bases physical distribution or structure. This work will reduce the cost of such investigations and enable data base intensive scientific research that would otherwise be unaffordable. Other work is under way to develop and test an expert system that can serve as an assistant to researchers analyzing space-derived data.

Research is being conducted to improve techniques for producing reliable computing systems. That work is directed at both reducing the number of faults in software and making systems that are tolerant to faults. New approaches and methods for software management and engineering have been devised and are now being evaluated under real working conditions. In addition, emphasis is being placed on the automatic reuse of software to lower software production costs. Future objectives in a new software engineering initiative will include research on the theoretical foundation and extending and evaluating approaches for developing reliable complex software.

The Computer Sciences Program is coordinated with the Space Station's Software Support Environment (SSE) and the DoD sponsored Software Engineering Institute (SEI) and ADA. NASA also participates with the DoD and other national bodies on several advisory and technical coordination committees.

Program Manager: Paul Hunter
NASA/OAET/RC
Washington, DC 20546
(202) 453-2704

Space Data and Communications R&T

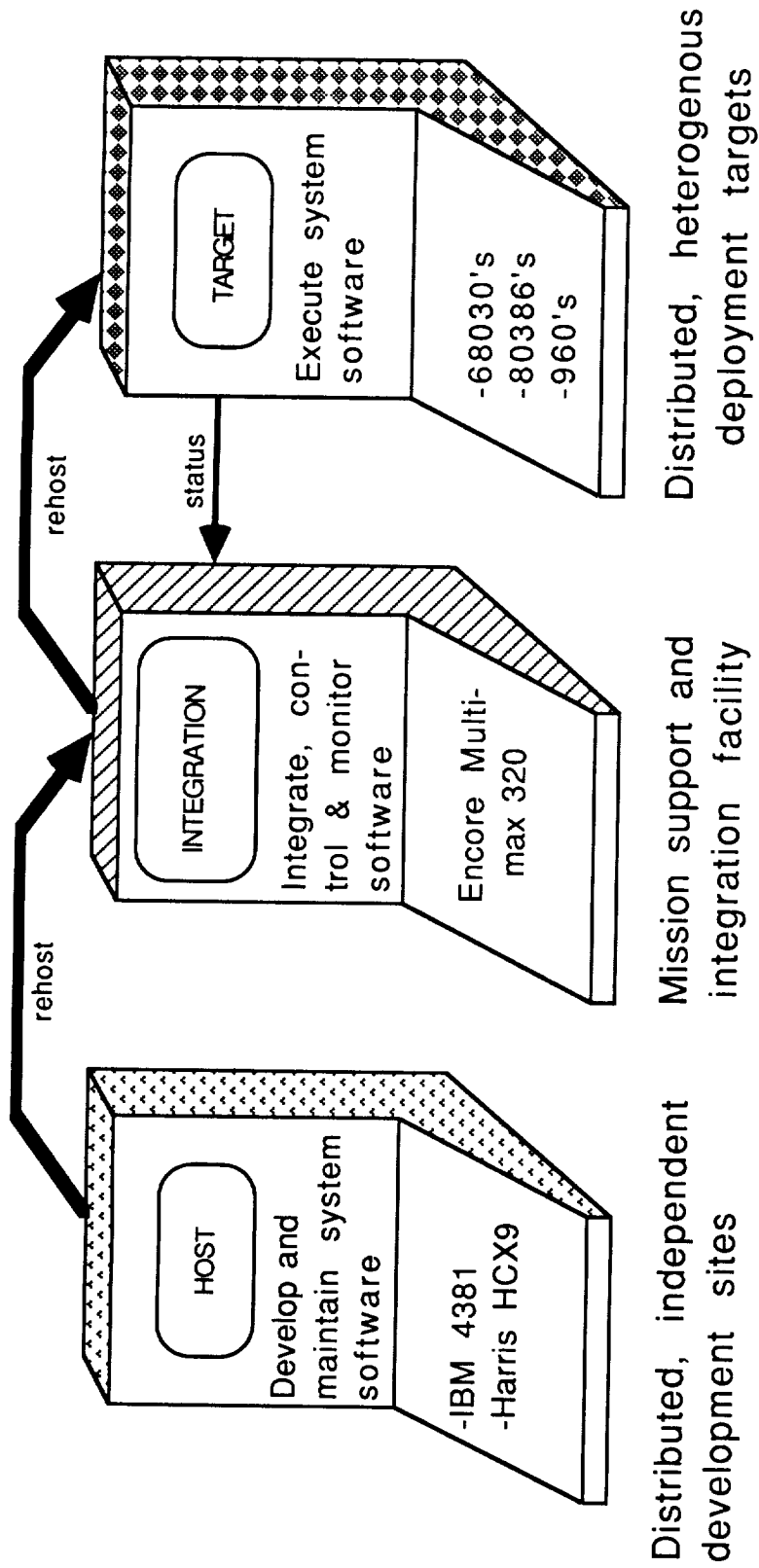
Areas of research in this RTOP include new models, methodologies, and paradigms to advance the life-cycle engineering of software, the development and maintenance of distributed information systems, advancements in operating systems and applications, software fault tolerance, use of Ada language and associated environments on NASA projects, and the application of Expert systems and Artificial Intelligence techniques to life-cycle software management.

This RTOP continues support of the NASA sponsored Software Engineering Research Center (SERC) within the Research Institute for Computing and Information Systems (RICIS) at the University of Houston at Clear Lake (UHCL). The SERC provides a means of focusing NASA research into software engineering issues and also provides a formal liaison with other similar centers of research. The SERC transfers its software engineering research results to NASA institutions and programs. Research undertaken in this RTOP is related directly to the implementation and management of computing and information systems used on NASA missions. Mastering new technologies in the areas noted is essential to accomplishing our goals. Although much of this research has significant potential for lowering the life-cycle costs of software, the principal thrusts (maintainability, modularity, and reliability) are more important and have a greater potential for return on investment. The work is focused on gaining new insights and developing better approaches to engineering the life cycle of software which is critical to the support of lives, health, property, the environment, and missions.

The research team of SERC was credited by NASA as a major influence in the decision to baseline Ada for the Space Station *Freedom* Program. SERC has actively worked to initiate complementary standards for the Ada language, with particular emphasis placed upon the run-time environments. SERC developed the model for Life Cycle Support Environments especially for the Software Support Environment (SSE) of the Space Station *Freedom* Program. SERC also developed several conceptual models, such as the model for a Distributed Object Based Information System, especially designed to advance the edge of knowledge for SSFP applications. SERC also works to transition advancements for software engineering into NASA and the NASA constituency. The Portable Common Execution Environment (PCEE) project is intended to produce a set of integrated conceptual models mapped to a three-part testbed which will demonstrate proof-of-concept of new approaches to managing life-cycle complexity of large complex systems such as SSFP.

Technical Contact: Bill Ho, JSC, (713) 483-4936

Portable Common Execution Environment



Autonomous Exploration

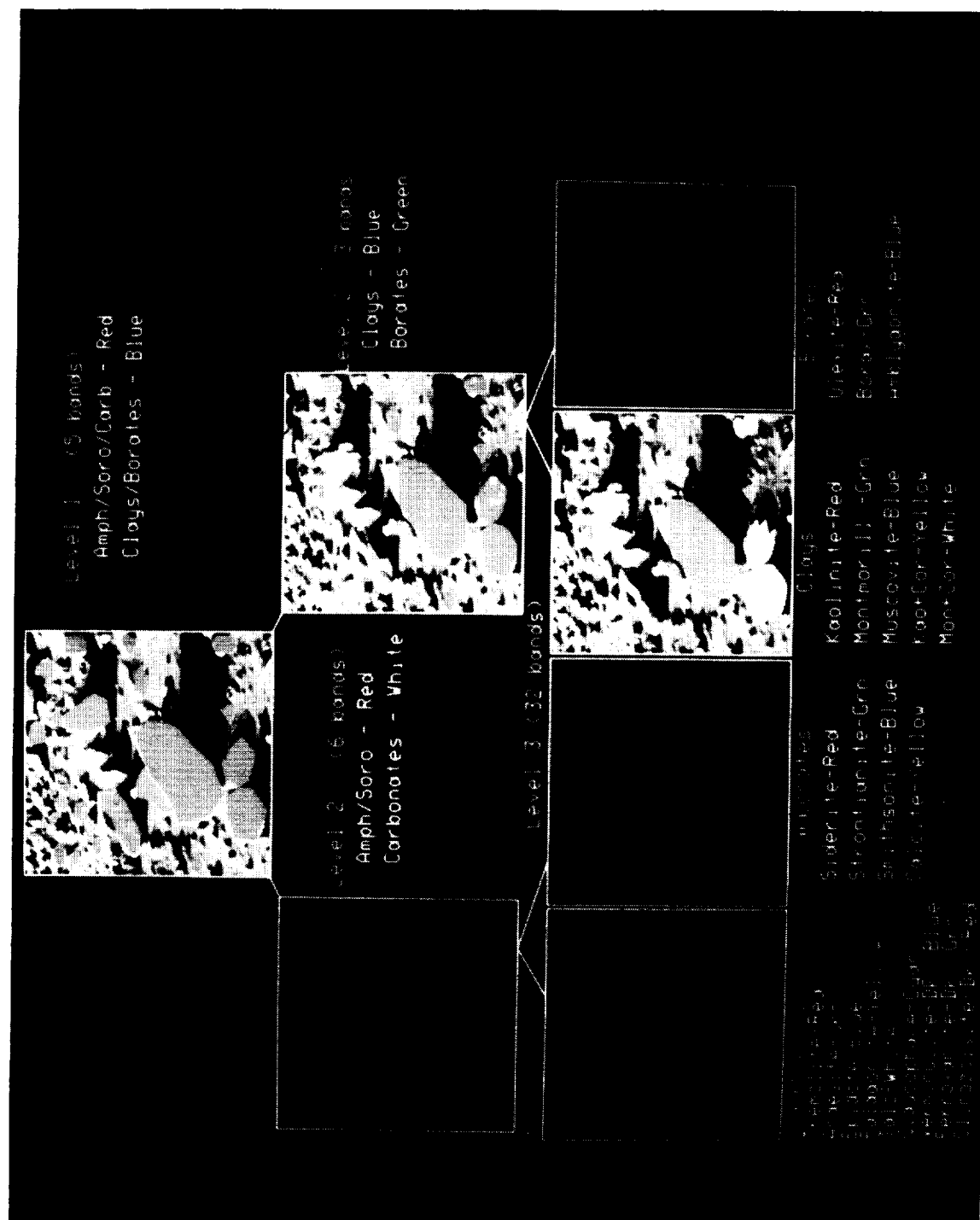
Scientific and imaging instruments for spacecraft and planetary exploration are increasing in complexity and sophistication, resulting in very high data rates. Instruments such as imaging spectrometers offer immense capabilities to remote sensing missions or to autonomous roving vehicles for planetary exploration. However, bandwidth limitations prevent transmission of more than a small fraction of the data to Earth, and the dynamic nature of the missions requires real-time interpretation of the data. To exploit the instrument capabilities, methods must be developed for real-time, autonomous information extraction, multisensor fusion, and decision making to drive instrument reconfiguration.

The objectives of this task are to develop and implement autonomous, real-time methods of high-dimensional image data reduction and information extraction, to fuse information from multiple sensors, and to provide autonomous decision making, driven by the scientific goals of the mission. A hierarchical, multiresolution approach to interpretation of both spatial and spectral data allows detailed investigation of interesting image areas while minimizing both computational cost and size of the output dataset. Analysis starts at low resolution and zeros in on regions of potential interest. This approach requires real-time decision-making capabilities to reconfigure instruments for further data collection.

A prototype system, developed to work with single-band visible image data and multispectral images, incorporates region finding and segmentation of visible images that allow interpretation on a region by region, rather than a pixel-by-pixel basis; multiresolution, hierarchical spectral classification that uses a few, select spectral bands at each classification level to produce detailed analysis of interesting areas with minimal computation; goal driven analysis that searches for interesting regions and prevents detailed analysis of uninteresting areas; and automatic decision making that includes reconfiguration of instrument parameters such as spatial and spectral resolution and spectral passbands. The result of this analysis is a compact, detailed description of each interesting region in an image, with a minimum of information on the other image areas.

Technical Contacts: Susan J. Eberlein, JPL, (818) 354-6467
 Jerry E. Solomon, JPL, (818) 354-2722

Autonomous Exploration



Concurrent Processing Research

The objective of this work is to perform fundamental research, by developing algorithms that map efficiently to computers with both very large numbers of processors and high-speed connections between the processors, for application to NASA problems.

The approach has been to implement a wide variety of applications on the highly parallel Single Instruction-Multiple Data (SIMD) architecture of the Massively Parallel Processor (MPP) in order to understand the robustness of this type of computer.

During fiscal year 1989, two types of algorithms, neural network simulation and cellular-dynamical systems simulation, were developed to run in the MPP array unit. Both are extremely computer intensive and map very well to the MPP's mesh architecture. The performance of these algorithms benefits greatly from the bit-serial nature of the MPP processors.

In neural Network Simulation, neural networks were implemented and used to solve clustering problems and multiple line-fitting problems. These computationally hard (NP-complete) problems are typical of a class of problems in data fitting, pattern recognition, and computer vision for which good, but not necessarily optimal, solutions are required. This work was performed in collaboration with the Center for Automation Research at the University of Maryland. Programs were written in the MPP Pascal language.

Cellular dynamical systems provide useful models for systems such as neural membranes, heart muscle, reaction-diffusion devices, and microeconomic communities in Cellular Dynamical Systems Simulation. They are made from finite sets of identical dynamical schemes by a complete graph of coupling functions and are particularly well suited to implementation on massively parallel machines. This work was performed in collaboration with John Corliss/Georgetown University and Ralph Abraham/UCSC. Programs were written in the MPP Parallel Forth language.

Two successive versions of a compiler for a generic fine-grained parallel *C* language (first defined in fiscal year 1988) were implemented. The second version is based on the ANS *C* language standard with parallel extensions. It is now being validated. The motivation for the development of this *C* language and its computational libraries is to define and develop ways that allow user programs to port between new massively parallel and heterogeneous hardware architectures as they appear.

In fiscal year 1990 research will continue on the simulation of cellular dynamical systems and the application of sorting as a data-routing utility on massively parallel computer architectures. For the generic fine-grained parallel *C* language, both the standard serial ANS *C* library and specialized parallel application specific libraries will be implemented and code generated by the compiler to various architectures will be targeted.

Technical Contact: John E. Dorband, GSFC, (301) 286-9419

Concurrent Processing Research

ACCOMPLISHMENTS

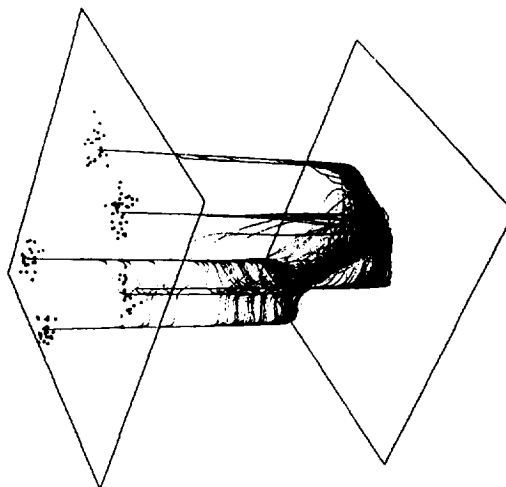
Demonstrated running in the MPP array unit:

- Neural Network Simulation (enhanced)
- Cellular Dynamical Systems Simulation (initial)

Produced an operating compiler for a generic fine-grained parallel C language.

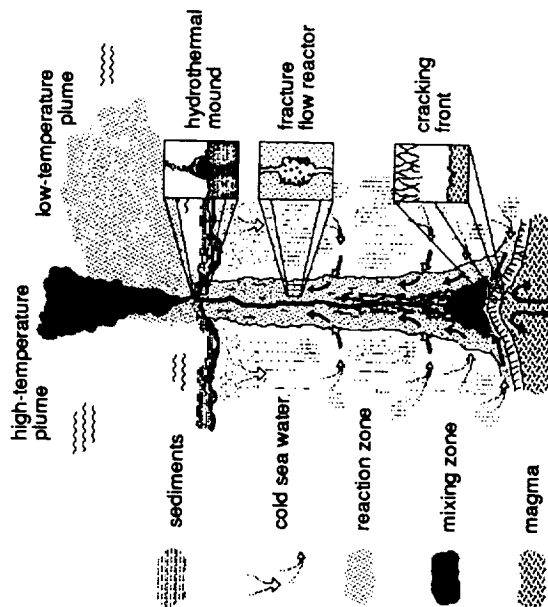
BENEFITS

- Image Understanding
- Physical System Modeling
- Higher Speed Fluid Simulation
- Portability of programs between massively parallel computers and heterogeneous hardware architectures.



Clustering on a Synchronous Neural Network

In this example, the data consists of 128 points distributed into five well separated clusters. Using the massive parallelism of the MPP, 128 different trials are performed simultaneously.



Cellular Dynamical Systems Simulation

By simulating on the MPP the chaotic behavior of dynamical systems such as those found in hot springs on the ocean floor, scientists may better understand the mechanisms of the origin of life.

Performance Characterization of Machine Architectures

The main objective of this program is to develop a new methodology for the evaluation of different machine architectures. The idea is to construct a model of a machine based on its execution time for source language program constructs. Separately, relevant source codes are analyzed. By combining the analyses, the performance of a given machine on a wide range of work loads can be evaluated.

Progress during fiscal year 1988 included the performance model being extended in several directions. With respect to the accuracy of the model, the number of parameters was increased from 76 to 102. This involved writing new experiments for the Machine Characterizer, changing the Program Analyzer and using it to update the data base program statistics, and making the necessary changes to the Execution Predictor. The new version of the system was used to collect statistics of 25 machines, including the CRAY Y-MP/832, CRAY-2, CRAY X-MP/48, IBM 3090/200, Ardent's TITAN-2, and Convex C-1. Currently, the data base is being increased, and reports and papers to make public the results are being written.

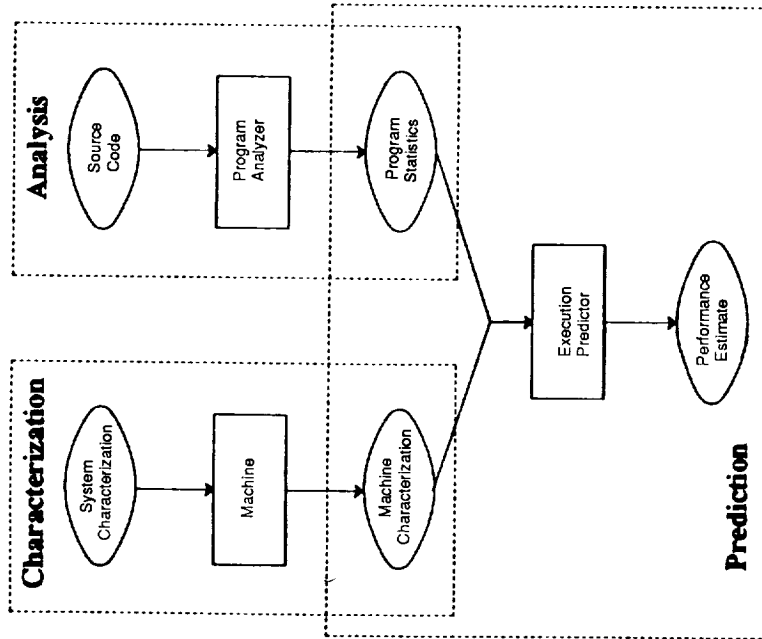
Several extensions to the performance model were investigated. These included defining a set of reduced parameters, based on the original 102, which makes it possible to do a more detailed comparison of the main architectural characteristics of the machines from the point of view of performance and using this set of parameters to define the concept of performance shape (pershape) that provides information about how a machine distributes its performance along different dimensions. Proposing a metric (pershape distance) that measures how similar two machines are with respect to their performance shapes and showing that the performance distance is a measure of how difficult it is to extrapolate the performance of a system knowing the benchmark results of another machine are also being investigated. The introduction of two metrics for program similarity that measure, in terms of the performance model, how similar different benchmarks are has application to the evaluation of the representativeness of a set of benchmarks.

A technical report was published by ARC (NASA CR 177511) describing the results of the first stage of this project. The report was also issued by U.C. Berkeley (UCB/CSD 88/437). Two papers were written which include most of the new results obtained in the last year. "Machine Characterization Based on an Abstract High Level Language Machine" was submitted and accepted for publication in the special issue on performance of the IEEE Transactions on Computers; that special issue was scheduled to be published in December 1989. "CPU Performance Evaluation via Benchmark Prediction" will be submitted for publication soon.

A project on the performance evaluation, via simulation, of the memory system of the CRAY-2 was started during the first months of the year. The simulation contains a detailed description of the CRAY-2 memory system and was used to evaluate the performance impact of several design alternatives, the memory chip latency, the capacity of the quadrant buffers inside the memory ports, the number of banks per quadrant, and the number of active processors.

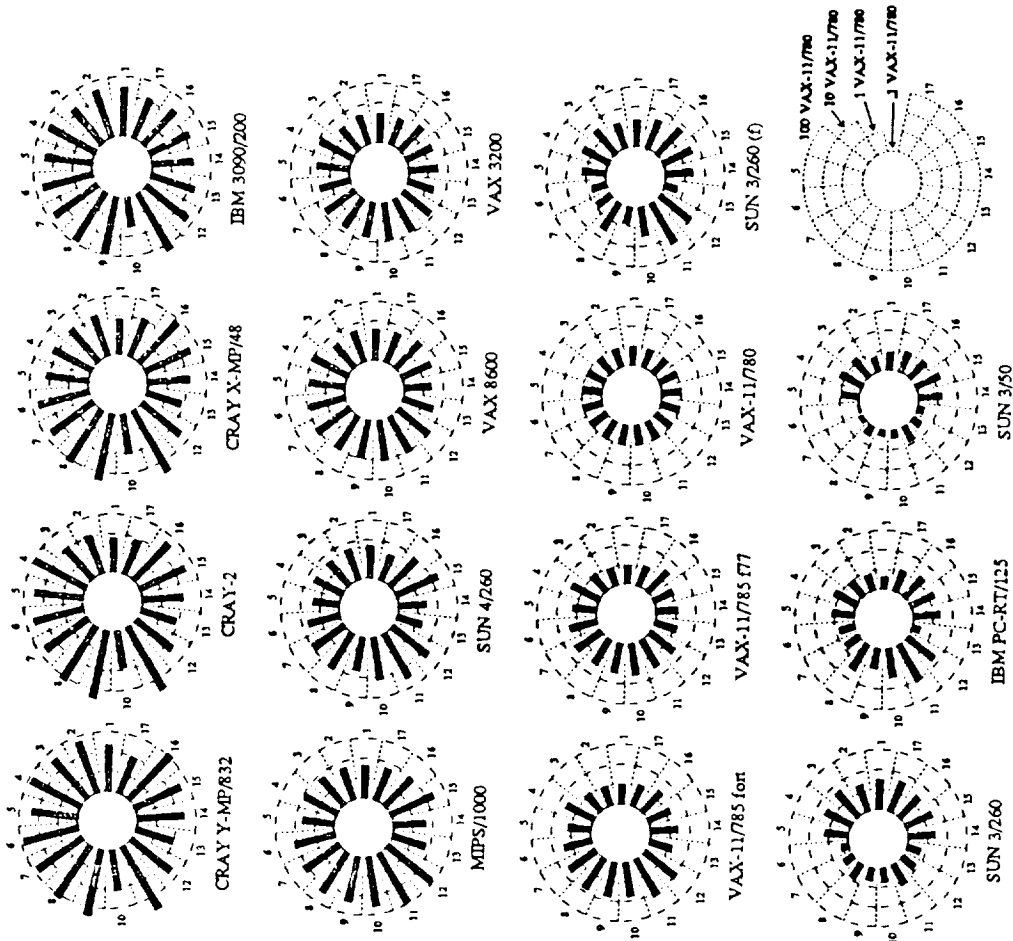
Technical Contact: Alan Jay Smith, U.C. Berkeley, (415) 642-5290.

Performance Characterization of Machines



- Characterization of machines
 - Fortran abstract machine model
 - Model with 102 parameters
 - Experimental measurement of parameters
 - Twenty-five system characterized
- Characterization of programs
 - Source code analyzer
 - Static and dynamic analysis
 - Program similarity metric
- Execution time prediction of applications
 - Prediction for small and very large programs
 - 62% of the predictions have less than 10% error
 - 97% of the predictions have less than 20% error

Performance Shapes (Pershapes)



Software Engineering Process Simulation

The objective of this task is to develop a realistic and meaningful intelligent based simulation model of the software development and management processes, to reduce software management complexity, and to improve product quality and schedule/cost savings via use of the model.

The main approach in this research is the use of the systems dynamics modeling and simulation technique to capture time-related causal relationships among software developmental and managerial activities. Various scenarios can be simulated. Optimal strategies for managing these possible scenarios and/or for improving a troubled software project can be tested and identified.

During the past decade, software project complexity and size are increasing with advanced technology. It has been shown that software development costs are growing exponentially. To help cope with these phenomena, many software project estimation and engineering tools have been developed. However, software development costs and schedule overruns persist. The software process simulation model being developed under the RTOP is very different from the static tools mentioned above (which assume the relationships among process components are static over time). This model focuses on capturing the dynamic characteristics of the process and modeling the time-related interactions among process components. The cause and effect relationships can then be better understood, and strategies for improving the project under study can be more intelligently selected.

This technology has been exchanged with many organizations, such as LaRC, SEI, GSFC, AT&T Bell Labs, Rockwell International, and others. Output from this effort is also being used by the IEEE Software Productivity Metrics committee. Future work will include refining the model, conducting a software project simulation workshop, transferring the technology to the JPL's Deep Space Network and other potential users, and incorporating AI technology.

Technical Contact: Chi Lin, JPL, (818) 354-4069



Intelligent Data Management Process

The objective of the Intelligent Data Management Project is the development of Intelligent Information Fusion (IIF) systems that integrate emerging software technologies using three-dimensional graphics, communications, object-oriented data bases, natural language query processing, connectionist models (neural networks), Artificial Intelligence techniques, and expert systems. The research into the utilization of these technologies will provide the basic information environment for NASA's planned space missions in the future.

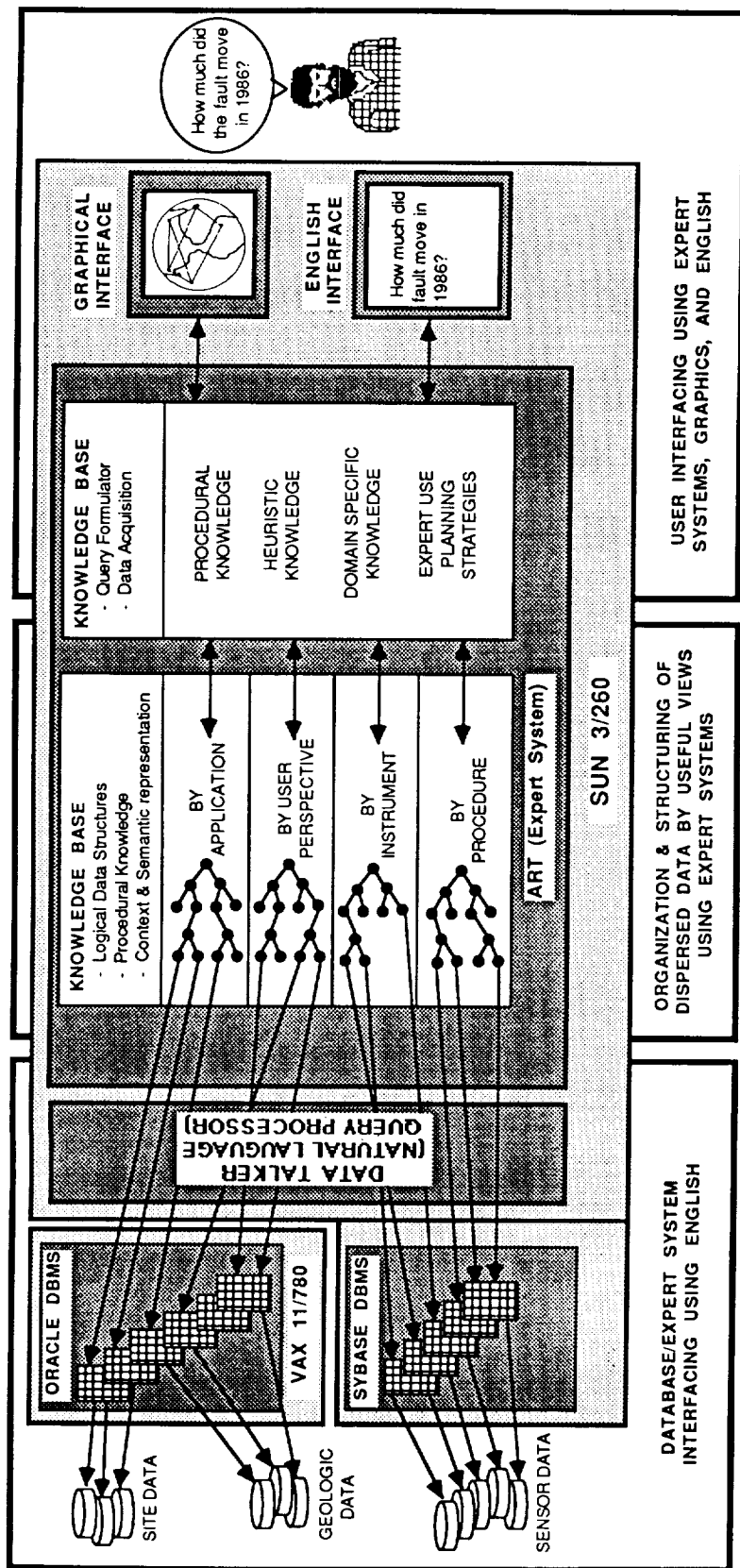
An advanced intelligent user interface prototype has been developed which remotely connects two distributed scientific data bases residing on different machines using two different operating systems:

APPLICATION		
Data Base Operating System Machine	Crustal Dynamics	International Ultraviolet Explorer
	Oracle VMS VAX 11/780	Sybase UNIX Sun

Using a natural language interface, a user can query each system spatially, with three-dimensional graphics, or can query temporally, without having any knowledge of the system architecture, data content, or language. This work was presented at the 1989 GSFC AI Conference and received an "Honorable Mention Award."

Technical Contact: William J. Campbell, GSFC, (301) 286-8785

Intelligent Data Management Process



OBJECTIVE

Development of an Intelligent System That Is Based On A Distributed Architecture With Value Added Services For Managing, Meta Data (Information About Data), Spatial Data, & Object Oriented Data In The Context of A User's Domain

BENEFITS

- User Does Not Have To Understand The Database Architecture, Query Language, or Data Content
- Will Allow Scientists To Access Multidisciplinary Data In A Common Environment
- Supports An Understanding Of The Data In Context By User, Application, & Source

FY 89 ACCOMPLISHMENTS

- Installed & Customized Expert System to SUN Workstation
- Installed & Customized Natural Language Query Processor "DATA TALKER" on SUN Workstation
- Installed, Customized, & Interfaced 3D Graphics For Two Scientific Operational Databases
- Knowledge Engineered & Interfaced Astrophysics DBMS Using ART
- Demonstrated The Entire Prototype With Two Scientific Operational Databases
- Tested & Validated IDM Concept Using Selected Noncomputer Oriented Scientists
- Presented & Published Results Of Prototype Research Effort

Image Data Encoding, Understanding, and Management

More automated methods of accessing and managing image data are needed in order to deal with large data volumes produced by sensors with high spatial and spectral resolution, to analyze large-scale and long-term trends, and to locate interesting features for scientific analysis. Current research is focused on three important components of this problem. These components are automated image segmentation for image data encoding, neural networks for image data understanding, and an object-oriented data base system for organizing and retrieving image features.

Improvements are being developed in two approaches for identifying regions of similar pixels in imagery. One approach uses iterative parallel region growing to segment the image data into regions of the same entity, and the other approach uses edge detection to find the edges of the regions.

The iterative parallel region growth approach has been highly refined during the past 6 months. The refinements include developing a merge control approach where the optimal merges within a set of variable, overlapping subimages are performed in each iteration. A new region comparison criterion based on preserving image entropy was developed to go along with the previous criteria based on minimizing image mean square error. The algorithm has been tested on a noisy simulated checkerboard image and on two TM images with great success.

The edge detection work has tested edge detection methods due to Canny (J. Canny, "Computational Approach to Edge Detection," *IEEE Transactions on Pattern Analysis and Machine Intelligence*, Vol. PAMI-VIII, Nov. 1986, pg. 679-698) and Nalwa (V. S. Nalwa and T. O. Binford, "On Detecting Edges," *Ibid.*, pg. 699-714). This work has found satisfactory a combination of Canny's algorithm with edge focusing. Edge detection has the drawback that the edges often do not form a set of closed connected curves that surround connected regions. In region growing, it is also often difficult to determine when to stop the region growing process. The edge detection aspect will help inform the region growing process when to stop growing regions, and the region growing aspect will ensure that the region edges form a set of closed connected curves.

A neural network approach has been developed to analyze image pixels and is currently being adapted to analyze the data in terms of regions. A three layer neural network has been implemented and has been tested with varying numbers of hidden nodes (middle layer). Neural network training time has been reduced through the introduction of a dampening factor, and the development of a hierarchical neural network approach has been initiated.

Technical Contacts: James Tilton, GSFC, (301) 286-9510
William Campbell, GSFC, (301) 286-8785

NASA Initiative in Software Engineering (NISE)

Goals: Develop highly automated software and systems engineering environments which utilize knowledge-based and reuse-oriented technologies along with a methodology for sustaining engineering

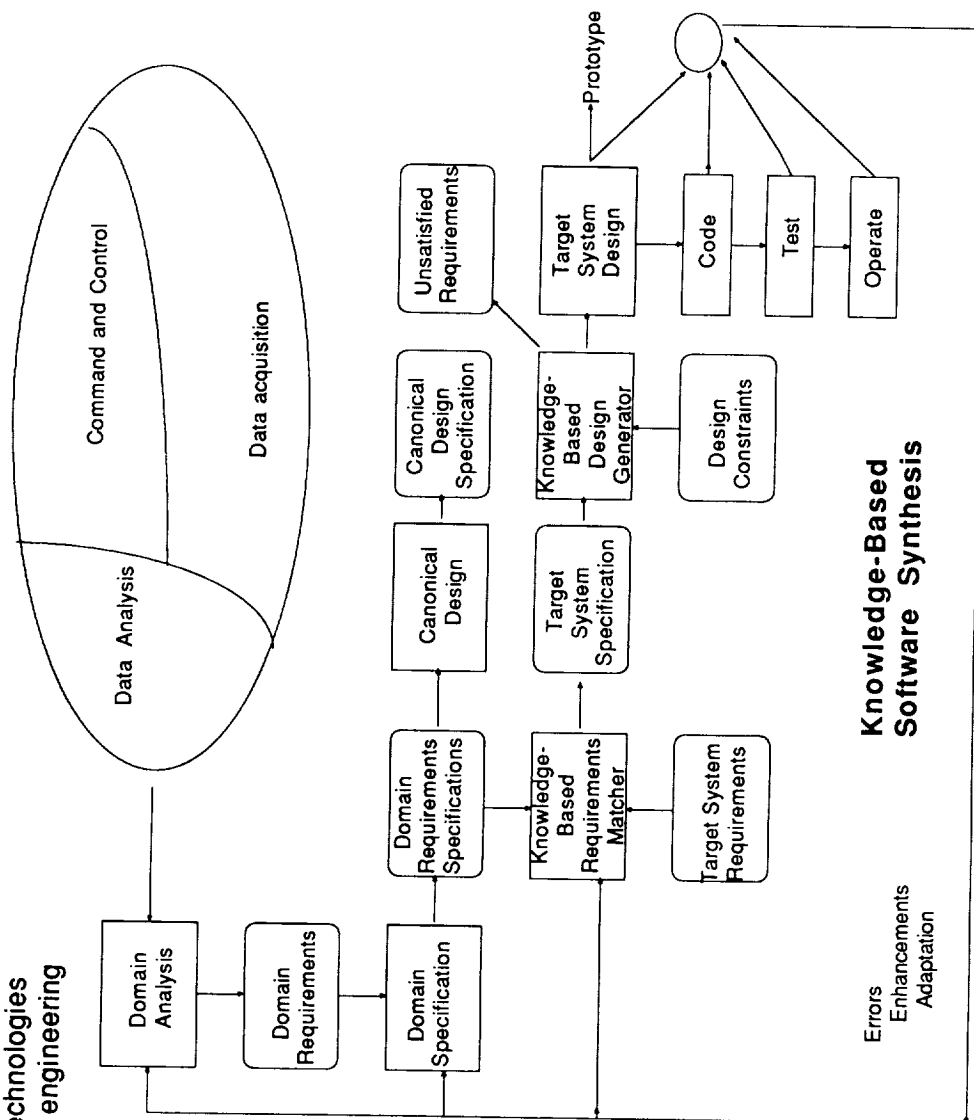
Accomplishments to date:

Operational approach to software reuse baselined.

Life Cycle Model which incorporates domain modeling for sustaining engineering developed.

Architecture established for a knowledge-based software engineering environment. It will use machine learning to build knowledge base of relationships between software components and application requirements.

Established industry (CTA) and Academic (George Mason University) participation.



The Software Management Environment

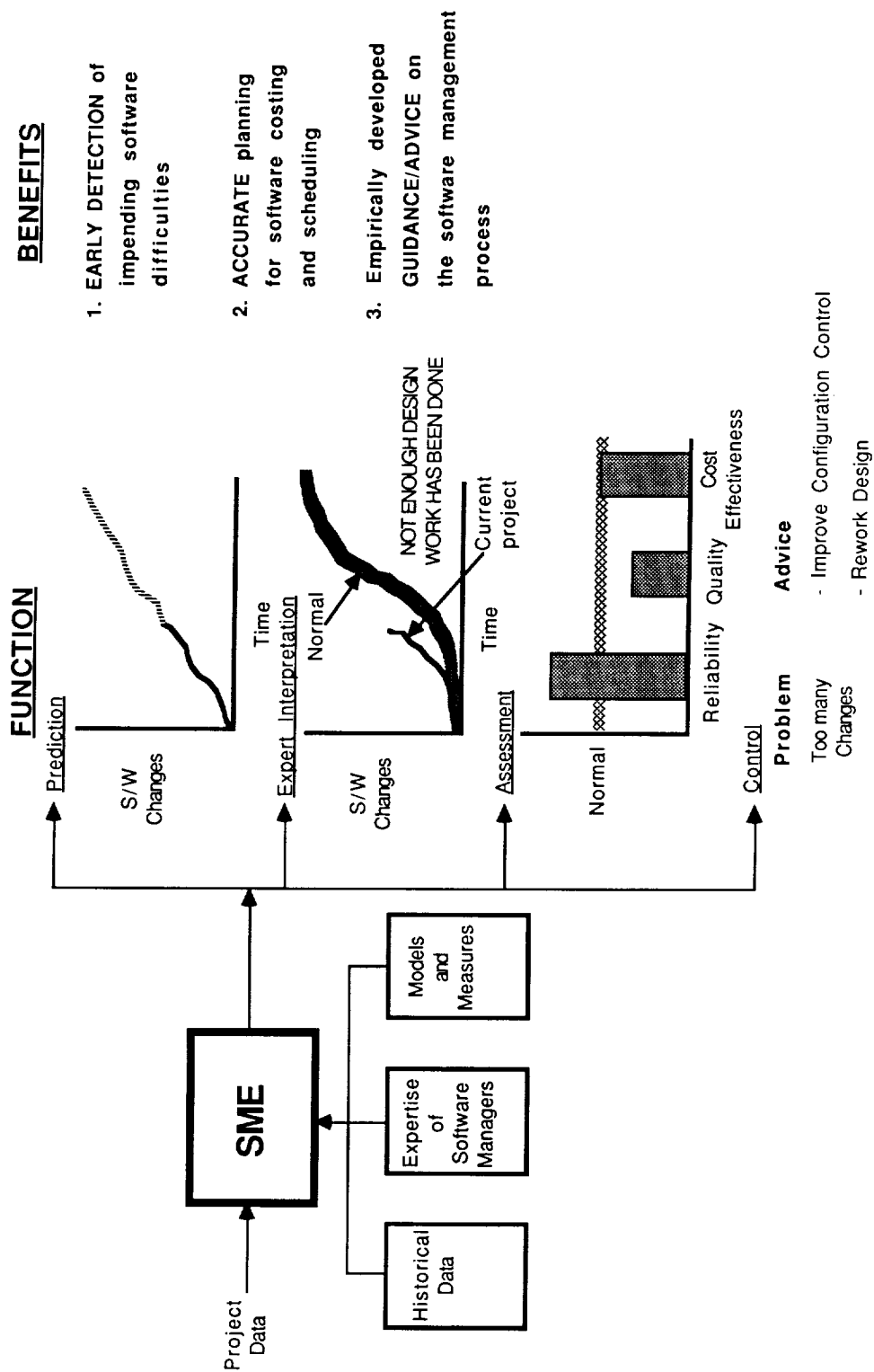
The Software Management Environment (SME) is a software tool designed to assist a manager in monitoring, analyzing, and controlling an ongoing software project. The major functions of the SME include tracking software project parameters, analyzing the differences between the current project's development patterns and the expected development pattern within the environment, predicting characteristics such as milestones, cost, and reliability, assessing the overall quality of the project's development process, and providing advice and guidance on management of the software project. To provide these functions, the tool continually examines available development data from the project of interest including manpower, software changes, computer utilization, and completed milestones and compares this information to data from past projects and to a model of the "typical" project.

Providing a set of capabilities that allows a manager to acquire pertinent, up-to-date information on the quality of a development project, the SME integrates much of the experience, results, and knowledge of major software engineering research that has been carried out in the Flight Dynamics Division at the GSFC. This research has provided a clearer understanding of the software development process within this one particular environment and the factors that lead to successful software projects. By integrating this knowledge with the knowledge of experienced software managers, the SME enables software managers to better understand, control, and analyze their software development projects.

Research accomplishments for fiscal year 1989 include the integration of algorithms for predicting future project status, the development of an initial expert interpretation function, and the enhancement of the models of software development parameters. During the next year the expert interpretation function will be integrated, research extending the estimation and prediction capabilities will be initiated, and a version of the assessment and guidance function will be developed.

Technical Contact: John Valett, GSFC, (301) 286-5316

Software Management Environment



Distributed Access View Integrated Data Base (DAVID) System

Space scientists and administrators at NASA must learn many different access methods to obtain data. This is due to the plethora of devices, such as IBM, VAX, CDC, SUN, and CRAY; of operating systems, such as Berkeley Unix, System V Unix, VAX/VMS, and IBM OS; of data base management systems, such as Oracle, Ingres, Sybase, Omnibase, IMS, and Adabase; of communication alternatives, such as ARPA Net, SPAN, Bit Net, and Local Area Net; and of data center protocols, such as those at the National Space Science Data Center and the Infrared Processing Analysis Center.

Access to distributed data, including access to complementary science observations in mission data bases and access to space system engineering data and project management information at centers and contractor subsystem facilities, is a major problem facing all segments of NASA.

This research deals with the development of a uniform method for accessing data that is layered on top of existing systems. This software system is called the Distributed Access View Integrated Data Base (DAVID) system.

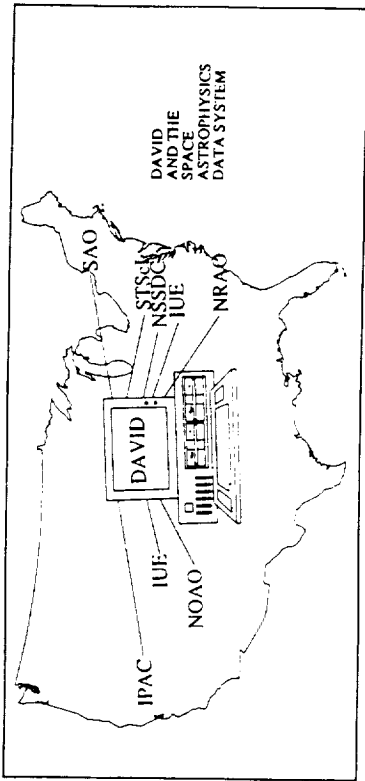
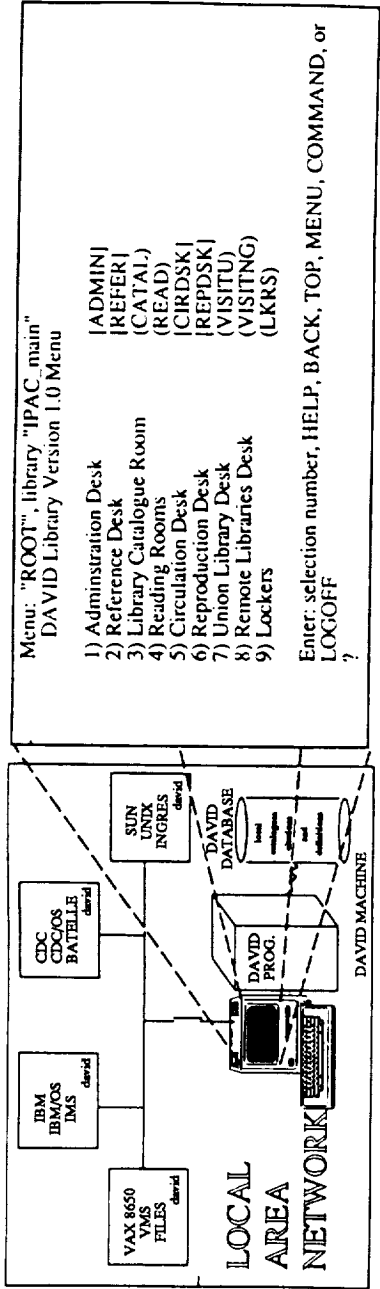
During the past year, the concept of an "Object Type Management System" (OTMS) was developed. An OTMS is a system that manages objects of a particular type in a manner similar to the way a Data Base Management System manages objects of type data base. Examples of managed types would be images, manuscripts, books, spreadsheets, and expert systems. In conjunction with the Astrophysics Division, the DAVID software was installed at 15 Astrophysics Data Systems Sites. These sites correspond to missions that have been or are planning to be flown. In conjunction with the Communications and Information Systems Office (Code EC), the DAVID software was installed at seven Earth Related Data Systems Interoperability Sites. These include two Pilot Land Data Systems sites at JPL and GSFC, two NASA Ocean Data Systems sites at the University of Colorado and the University of Rhode Island, the Coastal Zone Color Scanner System at GSFC, the NASA Climate Data System at GSFC, and the NASA Master Directory at GSFC. R-tree Gridding software was installed into the DAVID software. This feature can improve spatial search time from an order of n down to an order of $\log n$ steps. For the IUE Observation Log, the difference is a reduction of an order of 70,000 to an order of 16.

Currently, the direction of this research will be generalized from heterogeneous data base management systems to heterogeneous object-type management systems. In particular, specific heterogeneous object-type management systems for object types such as images, book, manuscripts, and experts, will begin to be developed. Work will continue with the Astrophysics Division on their Distributed Data System (which uses DAVID as its internal vehicle for accessing data) and with the Communications and Information Systems Office on their Interoperable Data Systems Project. Based on these experiences, improvements will be made to the DAVID software.

Technical Contact: Barry E. Jacobs, GSFC, (301) 286-5661

Distributed Access View Integrated Data Base (DAVID)

PROBLEM: • NASA SCIENTISTS AND ADMINISTRATORS HAVE TO LEARN MANY DIFFERENT SYSTEMS AND ACCESS METHODS IN ORDER TO OBTAIN DATA.



ACCOMPLISHMENTS

- BUILT AND TESTED VERSION 1 OF "MAIN ROOM" SOFTWARE FOR THE "LIBRARY LAYER" ON TOP OF THE DAVID ENGINE.
- BUILT AND TESTED VERSION 1 OF THE "READING ROOM" SOFTWARE FOR THE "LIBRARY LAYER" ON TOP OF THE DAVID ENGINE.
- INSTALLED DAVID SOFTWARE AT ASTROPHYSICS DATA CENTERS: IPAC, SAO, IUE, NRAO, NOAO, STScI & NSSDC.

CURRENT WORK

- WORK WITH ASTROPHYSICS DIVISION (CODE EZ) ON BUILDING A DISTRIBUTED DATA SYSTEM USING DAVID AS A VEHICLE FOR ACCESSING DATA.
- MAKE IMPROVEMENTS TO DAVID ENGINE/ LIBRARY LAYER BASED ON LESSONS LEARNED.

The Design and Implementation of a Preprocessor for the Ada Language to Support the Multiway Accept

The objective of this research was to design a programming language, Adam, that extends the Ada language to provide adequate support for a particular class of parallel algorithms and to develop a translator to translate programs written in the Adam language into input/output equivalent Ada programs.

Each algorithm in the class to be supported consists of an iteration of stages, where part of the work of each stage can be distributed among several processes. Algorithms of this type exist for applications such as multiplying matrices, sorting data, solving systems of linear equations, and plotting a moving point on a graphics terminal. The Adam language will permit the programmer to think in terms of centralized actions, and the translator will generate Ada code such that each action becomes decentralized and n such actions require time proportional to, at most, $\log n$ on a suitable parallel computer.

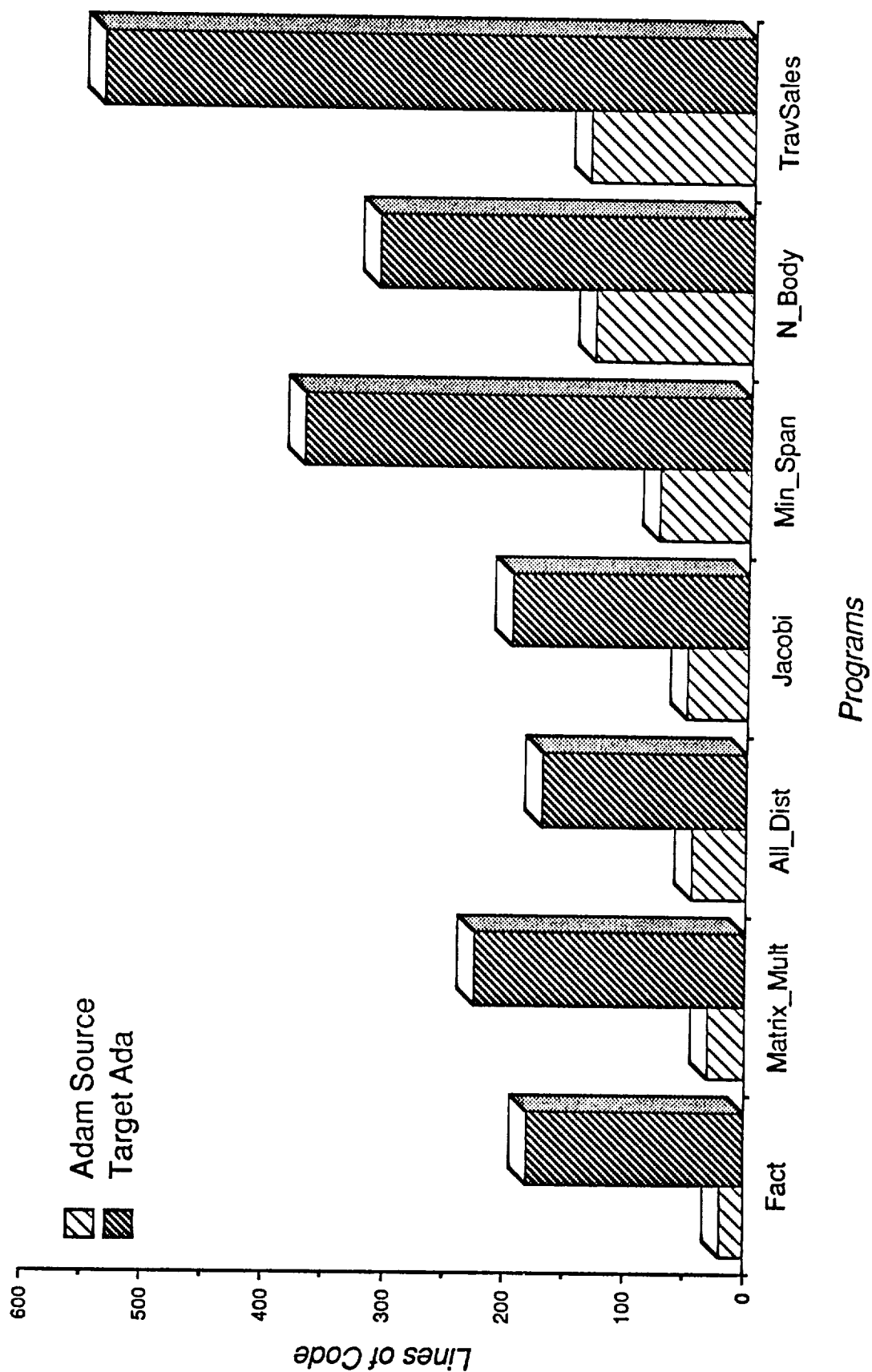
The Adam language currently includes two major extensions to Ada; a task in an array is allowed to access its array index, and the centralized multiway accept is provided for simultaneous communication between multiple tasks in an array. During the execution of a multiway accept, two additional centralized activities are permitted; predefined operations can be performed on sets of parameters, and assignment operations can be performed on arrays. The Adam translator successfully translates such programs into Ada code for either a sequential computer or a hypothetical parallel computer permitting concurrent access to shared memory and permitting processors to communicate within a hypercube topology.

Parallel programming is more difficult than sequential programming although many algorithms can be implemented adequately only on parallel machines. The Adam language permits programmers to write programs that are as simple as sequential programs for the class of algorithms in question, leaving the primary burden of difficulty on the language translator. Test coding of well-understood algorithms showed that Adam programs required 70 percent to 90 percent fewer lines of code than programs written in the unassisted Ada language.

Temporary restrictions on the Adam language will be eliminated, the performance of the Ada translator will be enhanced, and user-defined set operations will be supported. The Ada code generated by the Adam translator will be ported to suitable parallel computers.

Technical Contact: C. Michael Holloway, LaRC, (804) 864-1701

Relative Code Sizes



Mentat: An Object-Oriented Macro Data-Flow System

The objective of this research was to design, develop, and evaluate a system to support an easy-to-use, transparent mechanism to increase parallelism in distributed and multiprocessor systems.

In recent years, distributed systems and multiprocessor systems containing large numbers of interconnected processors and computers have been used to support a broad spectrum of applications. It is difficult to write parallel programs making effective use of system resources in these systems. Efforts to increase parallelism and performance have concentrated on load balancing via remote procedure call and process migration. Concurrent with advances in computer systems and communications are advances in programming languages and software engineering. One such advance is the object-oriented programming paradigm. Another advance is the use of data-flow models. The approach taken with Mentat has been to combine the object-oriented paradigm with the macro data-flow model of computation. The macro data-flow model differs from the traditional data-flow model in two ways: some data-flow computation primitives retain state information and the data-flow graphs are dynamic. In Mentat actors are operations on objects.

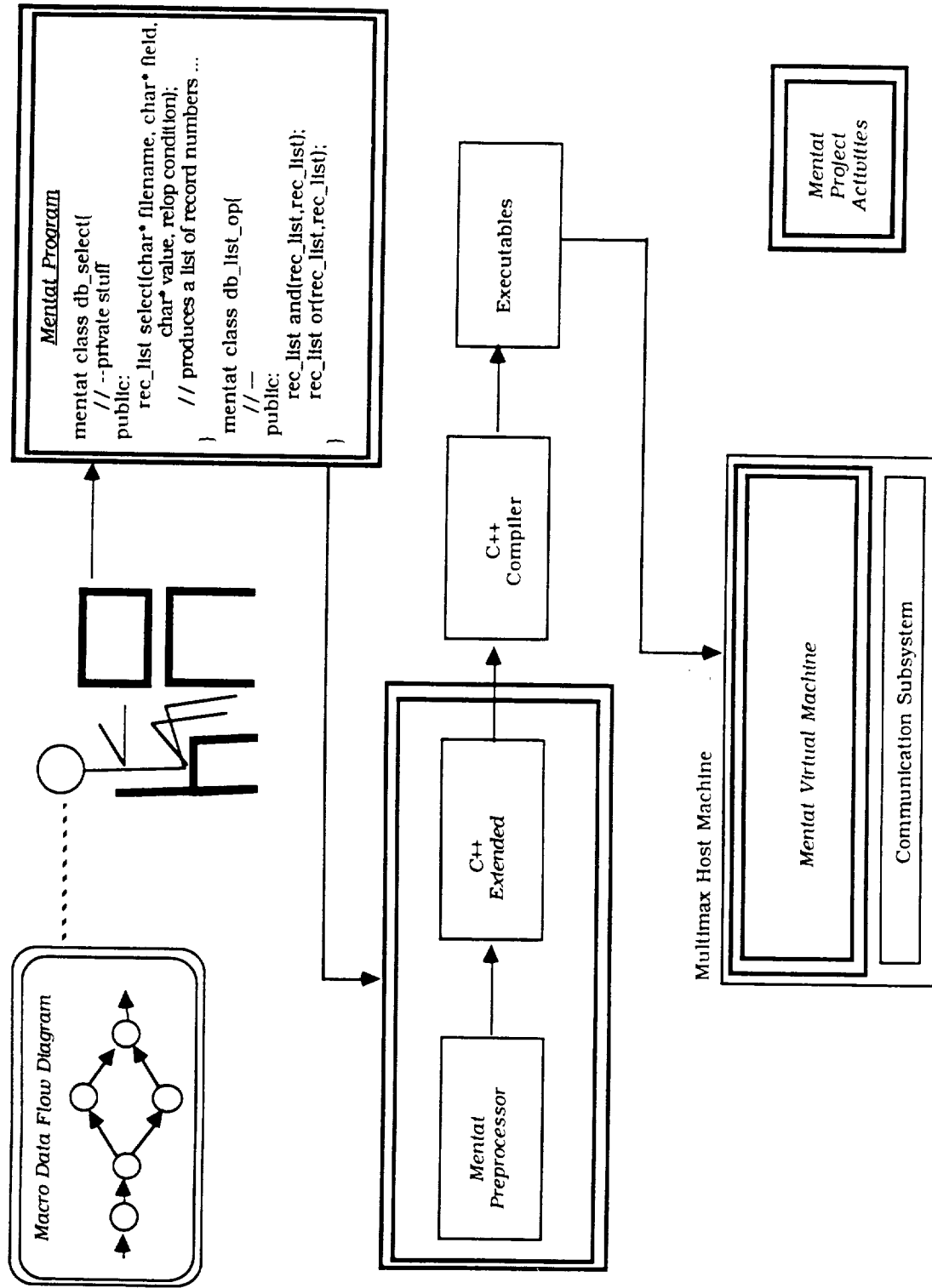
A prototype Mentat Macro Data-Flow System was designed and developed. The Mentat data-flow language was developed as an extension to the C++ programming language. In addition to hiding the implementation and data structures of objects, Mentat hides the parallel activities of objects. The Mentat preprocessor detects data dependency, generates data-flow graphs, and converts Mentat programs into standard C++ programs augmented with calls to library routines. These routines provide the interface to the Mentat virtual macro data-flow machine. A prototype Mentat virtual machine to emulate macro data-flow programs was implemented on a ten-processor Encore Multimax Computer. This prototype allows different hardware architectures to be simulated. The Mentat language and the macro data-flow approach were evaluated and their benefits identified.

The combined data-flow and object-oriented approach makes writing parallel programs easy. The use of persistent actors provides an effective means for interprogram communication. Experimental results show that the overhead of graph construction is approximately an order of magnitude less than the overhead of control actor execution. Performance data collected from executing several benchmarks demonstrated that Mentat supports large-grain parallel execution of distributed programs effectively.

Mentat is being extended in two different directions. An improved prototype is being developed on a message-passing system at the University of Virginia. Program constructs and deadline-driven scheduling primitives for hard real-time applications are being added to the Mentat language and virtual machine at the University of Illinois. These new efforts are supported by the Universities and the Office of Naval Research.

Technical Contact: Kathryn Smith, LaRC, (804) 864-1699

Application of the Mentat Macro Data-Flow System



Controls and Guidance - Aeronautics

The overall objective of the Aeronautics Controls and Guidance Program is to provide a validated technology base leading to the development and exploitation of new concepts, analysis/design methodologies, and flight systems for future civil and military aircraft. This technology base will provide increased efficiency, effectiveness, reliability, and safety for new aircraft. The program is organized in broadly applicable, generic elements and more focused vehicle-specific elements. The generic elements are Control Theory, Guidance Technology, and Flight Crucial Systems. Vehicle specific elements are Generic Hypersonics, Subsonic Transport/Commuter/General Aviation, Rotorcraft, and Fighter/Attack.

Research in the Control Theory element is directed toward the development of improved flight control analysis/design methodologies for highly integrated, robust flight control systems. These methodologies will account for strongly coupled, nonlinear plant dynamics. In order to develop an understanding of the dynamics of new vehicles, such as VSTOL and High Alpha research vehicles, system and parameter identification methods are being developed. New control approaches and concepts are exploiting emerging technologies such as Artificial Intelligence. Research in the Guidance Technology element involves the development of satellite precision navigation concepts and advanced technologies for wind shear detection and avoidance. Flight Crucial Systems research is directed toward the development of design, assessment, and validation methodologies for flight crucial systems. Increasing emphasis will be placed on developing engineering tools that support cost-effective certification of digital systems in flight crucial applications.

Research in the Generic Hypersonics element is focused on the development of multidisciplinary modeling methods, integrated aero/propulsion controls, handling qualities criteria, and trajectory optimization for hypersonic vehicles. In the Subsonic Transport element, activities are directed toward technologies that will provide more efficient civil transport operations in the future National Airspace System. The development of efficient 4-D guidance/control systems leading to enhanced efficiency and capacity in the terminal area is a major thrust in this element. Technology developments in automated mission management and goal-directed flight path management leading to automated nap-of-the-Earth flight capability are areas of emphasis in the Rotorcraft element. Research in the Fighter/Attack element is focused on advanced guidance and control concepts for future superagile aircraft, development of automated flight test techniques, and the development of multidisciplinary design methodologies for highly interactive dynamic systems.

The Aeronautical Controls and Guidance Program involves analytical and experimental research performed by in-house, university, and industry personnel. Extensive use of ground-based simulation is a characteristic of the program with selected flight experiments in a variety of aircraft. More emphasis is being placed on carrying the most promising concepts into flight evaluation and validation programs.

Program Manager: P. Douglas Arbuckle
NASA/OAET/RC
Washington, DC 20546
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Helmet-Mounted Display Synthetic Visibility System

The objective of this program is to define, develop, and evaluate a synthetic visibility system for performing safe, accurate, and consistent manual approaches and landings under visual meteorological conditions using video cameras and Helmet-Mounted Displays (HMD's) in lieu of a normal cockpit windscreen.

The study was conducted as a joint LaRC/McDonnell Douglas Corporation (MDC) program with MDC providing a proprietary state-of-the-art HMD system that was augmented by LaRC-determined supplementary symbology. LaRC interfaced the system with the Advanced Transport Operating Systems (ATOPS) B-737 aircraft and conducted flight tests to evaluate the effectiveness of the concept. The system provided forward-looking TV cameras mounted behind a window in the radome covering a field of regard 80 ° wide and 30° high. The TV scene was displayed on helmet-mounted eyepieces that displayed a 40° by 30° field of view, depending on the direction in which the pilot looked. A magnetic (Polhemus) sensor on the helmet sensed the pilots "look angle." An advantage of using HMD is that the scene can be displayed in actual size (magnification factor of 1), not a reduced size, to fit a head-down TV monitor. Superimposed on the TV scene was a set of supplementary symbology felt to be necessary to conduct a visual approach and landing. The symbology included airspeed, altitude and heading (all alphanumerics), flight path angle, longitudinal acceleration, airspeed error, flare cue, flight path reference line, waterline, and pitch ladder.

Flight test evaluation of the system was completed in June 1989 using two NASA and two MDC evaluation pilots. Development and data gathering flight tests involved more than 200 landings in a 32-hr flight test program. Results indicated the feasibility of HMD's for landing high-performance aircraft. Touchdown dispersions using HMD were comparable to visual landings. Thus, a synthetic visibility system for use in hypersonic vehicles may provide a suitable alternative to a traditional cockpit windscreen for pilots during approach and landing. A synthetic visibility system would provide huge savings in weight and complexity over a Concorde-type droop snoot.

Technical Contact: James R. Hall, LaRC, (804) 864-3851

Helmet-Mounted Display Synthetic Visibility



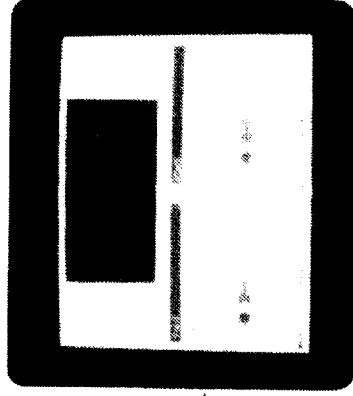
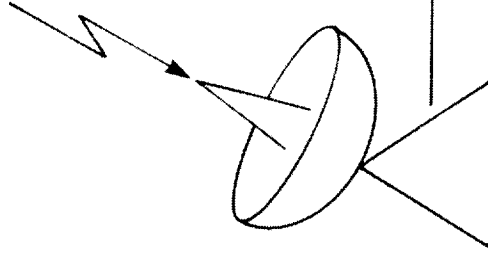
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Intelligent Computer Assistant for Engine Monitoring

The intelligent computer assistant for engine monitoring (ICAEM) is a workstation-based system for control room application which combines expert system and information display technology. This system is currently hosted on a MASSCOMP 5400 and uses the JSC-developed C Language Inference Processing System (CLIPS) inference engine. The ICAEM has been developed to enhance flight safety and increase productivity by providing an online, real-time mechanization of engine performance knowledge derived from senior and highly experienced propulsion engineers. The ICAEM has been developed to support the High-Angle-of-Attack Technology Program.

Technical Contact: Lee Duke, ARC-DFRF, (805) 258-3802

Intelligent Computer Assistant for Engine Monitoring



Workstation for real-time engine monitoring during flight research

Features

- Integrates information display and expert system technology
- Monitors engine from pre-flight through shutdown procedure
- Single real-time interface - data display
- Automated strip chart generation
- Anomaly classification and recovery displays

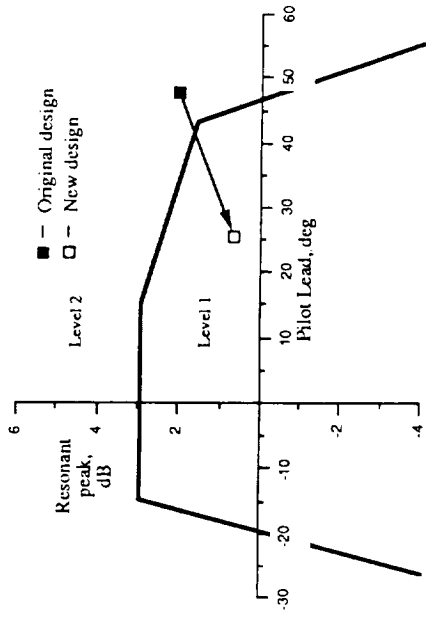
Advanced Design Technique for Improved Flying Qualities

Initial flight tests of the X-29A forward-swept-wing demonstrator indicated less than Level I flying qualities; this was because the initial set of control laws emphasized dynamic stability for the airplane that has very high levels of static instability in the pitch axis. After safely completing the envelope clearance of the X-29A, the task of improving the longitudinal handling qualities was undertaken. The task essentially consisted of eliminating the sluggish initial pitch response to pilot inputs, without compromising dynamic stability or placing excessive demands on the longitudinal control surface actuators. The process that evolved from this task is believed to have general applicability to fighter class airplanes for which a flight-validated simulator exists. The process begins with the application of the well-known Neal-Smith handling qualities criterion to the linearized version of the validated simulation. In this simulation, the control system gains are explicitly expressed. Next, a numerical parameter optimization is performed on all or some of the control system gains to obtain pitch-axis handling qualities that are optimal according to the Neal-Smith criterion.

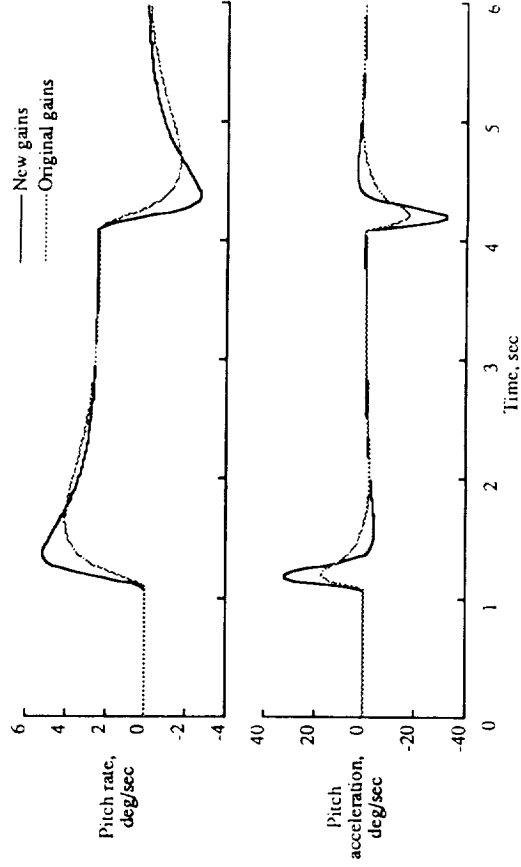
This process resulted in Level I handling qualities for the X-29A, a significant accomplishment that was verified by flight evaluation of the redesigned control system gains.

Technical Contact: John T. Bosworth, ARC-DFRRF, (805) 258-3792

Advanced Design Technique for Improved Flying Qualities



Neal-Smith Criteria



Key Features

- Uses Neal-Smith analysis procedure
- No flight control architecture modifications
- Improved pitch response
- Uses flight test results to fine-tune design

Automated Testing and Analysis Techniques

The objective of this project is to define, develop, and evaluate an online aircraft flight systems description that will be utilized as an engineering desktop tool that will assist engineers in the design, implementation, flight qualification, and maintenance phases of embedded flight control software. Gain schedules, software implementation details, control system architecture, mode logic, fault reaction, and redundancy management are typical examples of the type of information which will be contained in the data base.

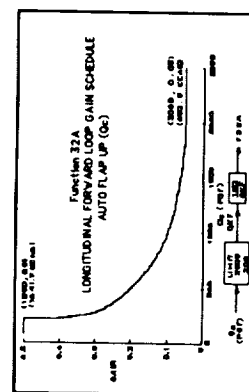
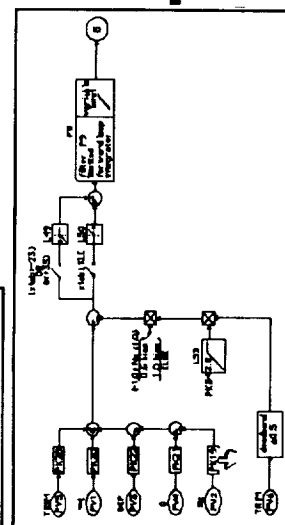
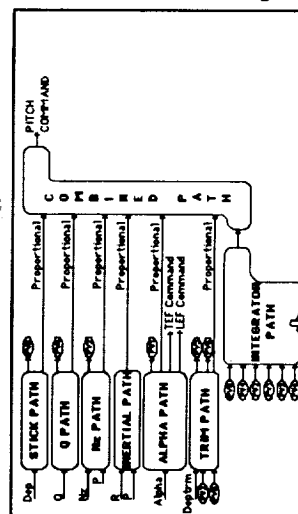
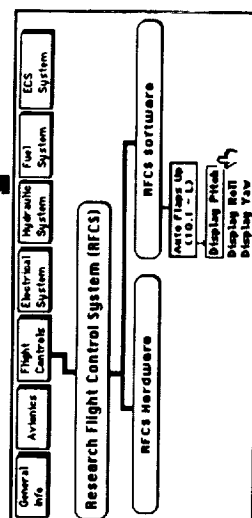
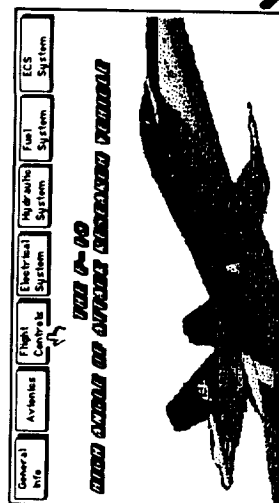
This particular data base will be used in conjunction with the automated testing capabilities currently being evaluated on the F-18 HARV project. Two major areas in the autotest environment to be evaluated are the utilization of the data base to assist the flight test engineer in constructing flight qualification procedures and the utilization of the data base to assist with aircraft simulation development.

One of the significant factors to consider in the cost reduction of testing embedded digital control systems is the information exchange between the implementers and the testers. The online data base will provide the flight engineer quick access to vital information needed to efficiently conduct the testing process. Links to the aircraft simulation are also being established. These links will assist the simulation engineer in simulating the control system with Ada. The links will also hide numerous simulation implementation details concerning the simulation test equipment that the tester currently has to relearn before every aircraft flight qualification process. The overall project productivity will be enhanced.

The aircraft data base concept was initially started on the X-29A program. The data base can be put in the control room to assist the flight test engineer in decoding fault logic code from the flight control computers during a flight. A more complete evaluation will be done on the F-18 High Angle of Attack Research Vehicle at ARC-DFRF. The F-18 HARV project data base is currently being designed, and control system information is being entered. A complete control system description was projected to be entered in the fall of 1989.

Technical Contact: Joel Sitz, ARC-DFRF, (805) 258-3666

Automated Testing and Analysis Techniques



- Online aircraft flight systems descriptions
- Links to simulation being established
- Automation providing enhanced productivity

The F-18 High Angle Of Attack Research Vehicle Project Database

Traffic Management Advisor

The Traffic Management Advisor (TMA) aids the flow controller in coordinating flights from multiple sectors through the generation of efficient landing schedules. The TMA includes algorithms, a graphical interface, and interactive tools for use by the Center traffic manager or TRACON controllers in managing the flow of traffic within the terminal area. The primary algorithm incorporated in it is a real-time scheduler that generates efficient landing sequences and landing times for arrivals within approximately 200 nmi from touchdown. Its graphical interface and interactive tools are designed to assist the traffic manager in monitoring the automatically generated landing schedules, to override the automatic scheduler with manual inputs, and to change scheduling parameters in real time.

TMA has been implemented on a separate workstation that is interfaced with the workstations running the descent advisors (DA's) at the various arrival areas. In essence, the scheduler is a real-time algorithm that transforms sequences of estimated times of arrival (ETA's) into reordered sequences of scheduled times of arrival (STA's) using one of several scheduling protocols selected by the traffic manager. Operation in real-time implies that the algorithm generates the STA's in a small fraction of the time it takes each aircraft to fly from its initial position to touchdown. One possible display configuration is illustrated in the figure. In the left window are three timelines, which are the first displays the STA's generated by the TMA. These scheduled times are sent to the appropriate arrival sector. The second and third lines provide ETA's. The window on the upper right gives an overview of traffic in the Center in a miniature primary vision display (PVD). The middle window gives the status of all DA's providing ETA data to and receiving STA data from the TMA. The window on the lower right acts as the traffic manager's control panel in which various scheduling parameters (such as the airport acceptance rate and the configuration of the timelines) are selected by mouse-actuated switches and sliders as well as keyboard entries. The TMA was included in the March 1989 simulation. The algorithms provided efficient schedules that were used as a basis by the sector controllers in managing traffic within the individual sectors.

The TMA is an essential element of a computer-aided air traffic control (ATC) flow management system. It provides the means for overall coordination of traffic in the terminal area. The display permits the controller to review planning information graphically in a configuration adjustable to his needs.

The TMA will continue to be evaluated and refined using the ATC simulation facility; ultimately, a live traffic test will be needed to establish the effectiveness with a high level of confidence.

Technical Contacts: H. Erzberger, ARC, (415) 694-5425
W. Nedell, San José State University, (314) 962-0985

Fiscal Year 1989 Simulations

During fiscal year 1989, a considerable number of simulations have been conducted on the Vertical Motion System (VMS), the fixed-base facility, and in the Automation Laboratory, which was dedicated during the year. Since the VMS began operation again in the summer of 1988, the simulation work load has been extremely heavy, both on the motion-based system and on the fixed-base system. In addition to the upgraded motion system, a new computer (the AD-100) has been procured, delivered, accepted, and used for research simulations. This AD-100 computer provides much greater computational capability and improved reliability than previous machines. The capability provided by the equipment in the laboratory also significantly improved.

The VMS and fixed-base facility supported a total of 20 major simulations during the year. The 20 simulations included 18 research simulations, a simulation to accept the new AD-100 computer, and a simulation to provide training for wind tunnel operators for rotorcraft tests (TUTOR). The research simulations included eight helicopter simulations; one Space Shuttle simulation; two short takeoff and landing (STOL) simulations (C-17); three tilt-rotor simulations (certification and MV-22); three STOVL (short takeoff and vertical landing) simulations; and one simulation technology simulation.

The Automation Laboratory supported one major ATC automation simulation in March 1989. The laboratory also supported development efforts both for the ATC Automation program and the Automated Nap-of-the-Earth (NOE) Program.

Technical Contact: Tony Cook, ARC, (415) 604-5162

Fiscal Year 1989 Simulations



VMS MOTION BASED OPERATIONS

TERRAIN FOLLOWING/TERRAIN
AVOIDANCE

R/C SPECIFICATION DEVELOPMENT

WASP (WIDE ANGLE SENSOR
PROJECTION)

VISUAL/MOTION SYNCHRONY

TILT ROTOR CERTIFICATION

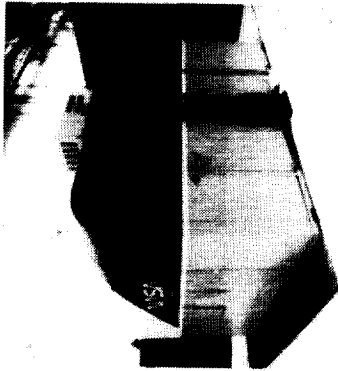
AD-100 ACCEPTANCE

UH-60 VALIDATION

SPACE SHUTTLE

RASCAL (2)

C-17 (2)



FIXED BASE OPERATIONS

MV-22

VSRA

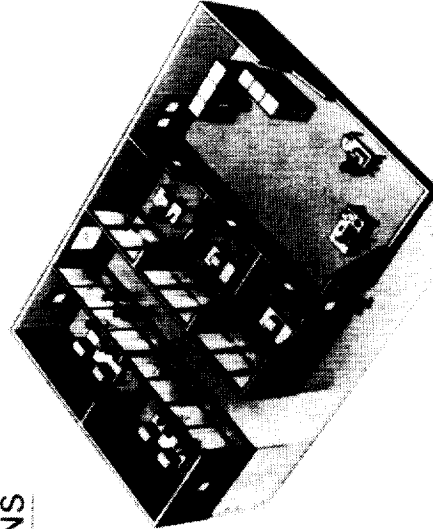
TILT ROTOR CERTIFICATION

STOVL

STOVL DECELERATING
APPROACH

HIMARCS

TUTOR



AUTOMATION LAB

ATC AUTOMATION

AUTOMATED NOE

Analysis of Records From Four Airliners in Denver Microburst, July 11, 1988

ARC, in cooperation with LaRC, the National Center for Atmospheric Research (NCAR), and the Federal Aviation Administration (FAA), has initiated an effort to determine the nature, cause, and extent of wind shear hazards through a detailed analysis of the flight records of four airliners that encountered microburst activity at the Denver airport on July 11, 1988. The data set available from this incident is unique because it includes flight records from multiple aircraft along with data from a prototype Doppler weather radar system. In addition, meteorological soundings, taken prior to the incident, were used to initiate a numerical simulation of the microburst. The initial goal of this research is to derive horizontal winds from flight data analysis and compare and augment these results with data from Doppler radar and the numerical model.

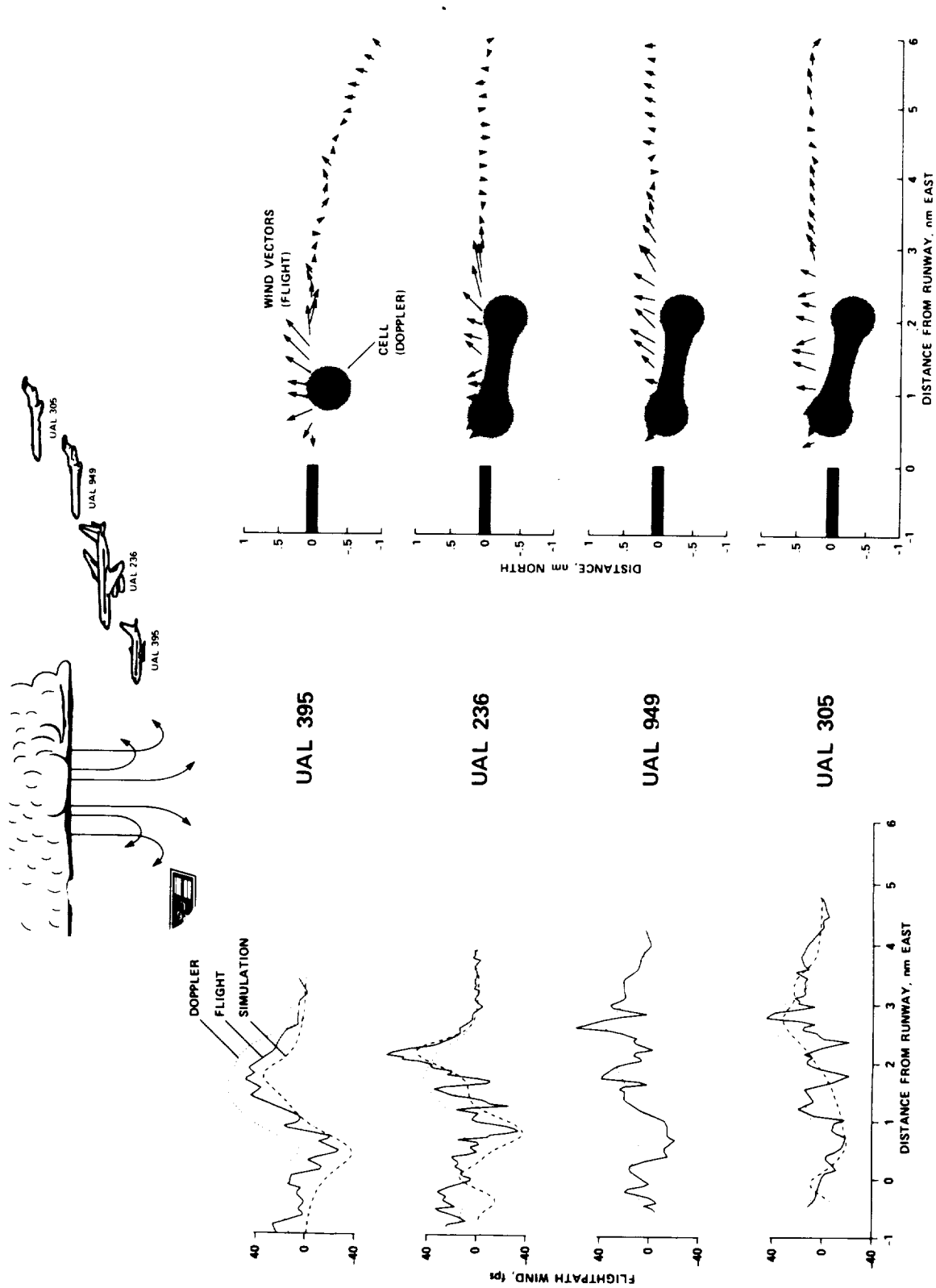
In order to derive horizontal winds from the flight records, ATC radar position data are utilized. Inertial speed is determined from the radar data, and the aircraft speed with respect to the air mass is determined from the flight recorder data; the differences between the two represent the winds along the aircraft flight path.

The four encounters provide information about the time-varying changes in the strength, size, and location of the microburst. The results show significant expansion in the size of the microburst and indicate the existence of internal velocity fluctuations. The second aircraft encountered a head-wind to tail-wind change of 115 ft/sec, which is the largest for all four aircraft. The developing wind pattern measured from the aircraft is in general agreement with the measurements from Doppler radar and the analytical results from the numerical simulation. The aircraft data complement these other findings by providing a more detailed analysis of the internal velocity fluctuations within the microburst. The Doppler data indicate that a second cell developed within the microburst at some time between the first and second aircraft encounters. This observation appears to be consistent with the wind vectors determined from the flight data. Furthermore, the velocity fluctuations experienced by the last three aircraft appear to have resulted from the two adjacent cells.

The ARC-derived estimates of the winds from the flight records onboard the four airliners provide a new detailed description of the turbulent wind environment in a severe microburst. The results show significant expansion in the size of the microburst and indicate internal velocity fluctuations that were apparently caused by multiple cells in the microburst. These findings will aid in the modeling of severe microbursts. Future emphasis will be on the modeling of dynamic flow fields with multicell and vortex-induced turbulence and on associated effects on aircraft operating problems.

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 R. Wingrove, ARC, (415) 694-5429

Analysis of Flight Records From Denver Microburst



VSRA Thrust Model Calibration for Aerodynamic Modeling

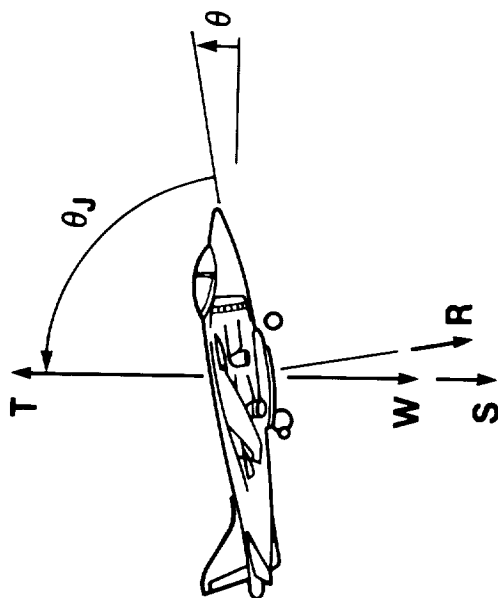
The objective of this program is to define and identify a full-envelope aerodynamic model of the V/STOL (vertical/short takeoff and landing) Research Aircraft (VSRA) from a flight test data base. The model must represent VSRA body forces and moments over a flight envelope that includes hover, transition to forward flight and back to hover, as well as STOL operating and normal cruise. The new aerodynamic model is needed to update a VSRA simulation that supports ongoing research in advanced control, display, and guidance concepts for STOVL aircraft.

Aerodynamic forces and moments acting on the VSRA in flight are determined as the difference between total forces and moments and propulsion system forces and moments. A nominal thrust model is used to compute thrust from measurements of key engine variables, such as r/min , Mach number, thrust deflection angle, and control positions. Because actual engine thrust may differ from nominal engine thrust by as much as 3 percent, the nominal thrust model must be calibrated to match flight test estimates of engine thrust. Analysis of hovering flight data has been used for thrust model calibration. The engine thrust in hover must balance the inertial forces, the control forces, and the aerodynamic suck-down force. The inertial and control forces may be computed from flight data. Suck-down is an aerodynamic force due to entrainment of ambient air toward the main engine jet in hover, and is equal to approximately 2 percent of thrust. Calculations of actual thrust and nominal thrust were compared for selected hover segments. The difference was converted to an equivalent scale factor applied to the measured engine r/min . This technique was used for two reasons. First, because measured engine r/min has the largest influence on modeled thrust, thrust model output may be easily scaled by scaling the engine r/min . Second, a measurement error in engine r/min would contribute significantly to a difference between actual and nominal thrust. A scale factor applied to engine r/min will correct the nominal thrust model in either case. Results indicate a consistent thrust correction equivalent to 2 percent engine r/min at the hover condition.

Because engine performance can vary significantly from nominal, a thrust model calibration must be performed when the model is to be used for critical force and moment computations. It should be emphasized that the aerodynamic model identified from flight test data can only be as good as the propulsion model used to isolate aerodynamic forces and moments. Aerodynamic forces and moments are being isolated from the data base using the calibrated thrust model. Aerodynamic modeling of the VSRA using parameter identification techniques is ongoing.

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VSRA Thrust Model Calibration From Hover Measurements



T - THRUST
W - WEIGHT
R - CONTROL FORCE
S - "SUCK-DOWN" FORCE

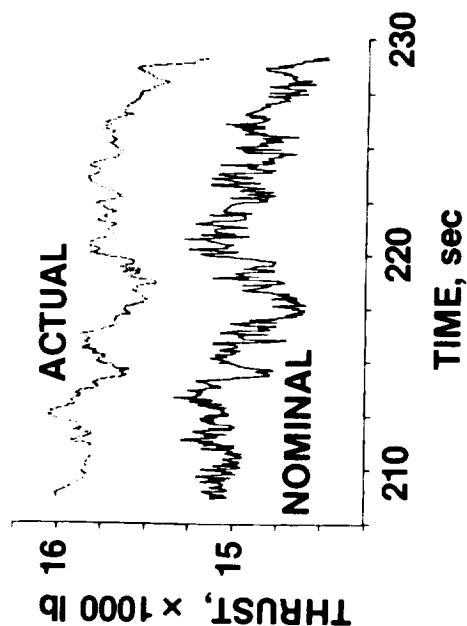
ACTUAL THRUST:

$$T = W(1 + \ddot{h}/g) + S + R \cos \theta$$

NOMINAL THRUST:

$$T = f(R/\text{MIN}, \text{CONTROL FORCE, ETC.})$$

- THRUST VARIATION FROM NOMINAL EQUIVALENT TO 2% R/MIN
- MEASURED R/MIN SCALED TO EFFECT THRUST CALIBRATION



Space Shuttle Approach and Landing

This simulation continued studies of the Space Shuttle orbiter landing and rollout issues relative to touchdown, steering, braking, deceleration, crosswind landing, and tire failures. Specific items under investigation were general purpose computer/nose wheel steering (GPC/NWS) control laws for heavy weight vehicles, drag chute design and transients from hardware tests, tire wear at KSC, carbon/carbon (versus beryllium) brakes with an antiskid system, and crew evaluations.

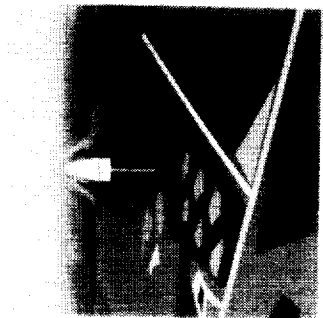
During the second week of the simulation, STS-30 landed at Edwards Air Force Base, and the crew experienced handling problems on the runway due to crosswinds gusting at higher than acceptable levels. A control problem occurred during landing at the initiation of nose-wheel-steering (NWS). Subsequently, the available gust profile data from the STS-30 landing were obtained and coded into the ongoing VMS simulation environment. Within 11 days of the landing, the STS-30 pilots were flying the VMS, with a reconstruction of the encountered conditions.

During the simulation of the landing, the NWS problem was discovered as a function of the enabling of NWS following weight-on-nose-gear (WONG). At that point, the nose wheel was in caster-mode, at an angle to the body axis, due to the residual yaw angle because of the crosswinds. The initializing logic for NWS caused the nose-wheel to center on the body X-axis, causing a sudden directional control problem for the pilots.

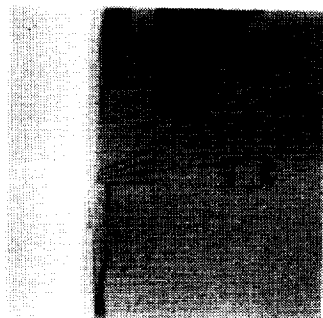
An engineering solution to the problem was developed during the simulation; this included a change in NWS initiation delay from 0.48 sec to 3.2 sec following WONG, and a change in NWS initial position from the 0 position to current (or feedback) position. These changes were then evaluated by 39 of the astronauts, submitted to the JSC Program Review Changes Board (PRCB), and approved for incorporation into the next flight (STS-28). All this was accomplished in a little more than 4 weeks following the STS-30 landing, while the VMS simulation was in progress. During the 6-week simulation investigation, 2018 Space Shuttle landings were performed for data, and more than 2500 simulated landings were conducted overall.

Technical Contact: Bob Showman, ARC, (415) 604-6207

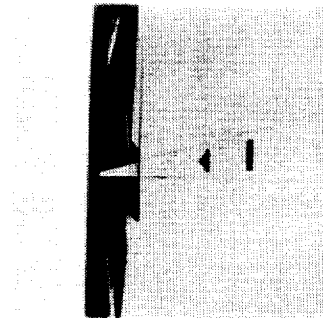
Space Shuttle Approach and Landing Sites



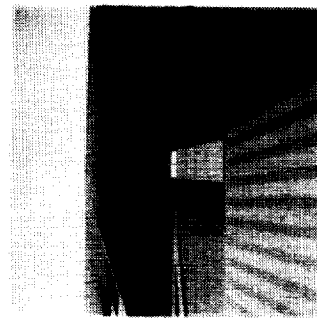
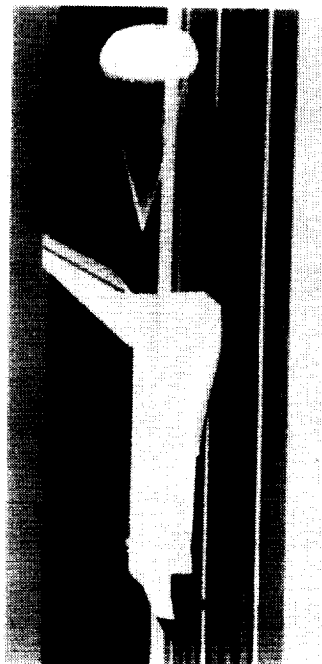
KENNEDY SPACE CENTER



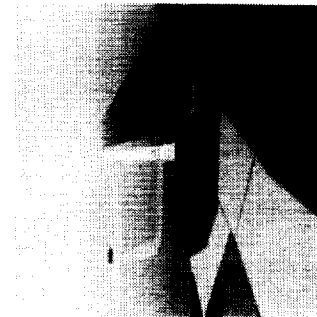
EDWARDS AFB RUNWAY 17



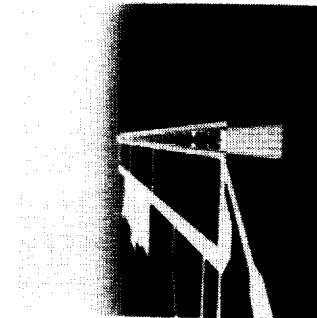
EDWARDS AFB RUNWAY 22



ZARAGOZA, SPAIN



BEN GUERIR, MOROCCO



MORON, SPAIN

Final Approach Spacing Tool

The advanced ATC Concepts simulation has been expanded to include TRACON operations and an automation aid referred to as the Final Approach Spacing Tool (FAST). FAST assists TRACON controllers in sequencing and spacing arrival aircraft for maximum runway throughput.

The concept is based on monitoring each aircraft's current state (position, airspeed, and heading) and predicting arrival time based on a nominal 4-D path to the runway, the aircraft's performance characteristics, and current weather conditions. Based on a conflict-free scheduled arrival time at the runway, an efficient path to the runway is synthesized using speed control, path stretching, and path modification. The suggested path and speed commands are displayed to the controller utilizing mouse-based functions and a color graphics interface.

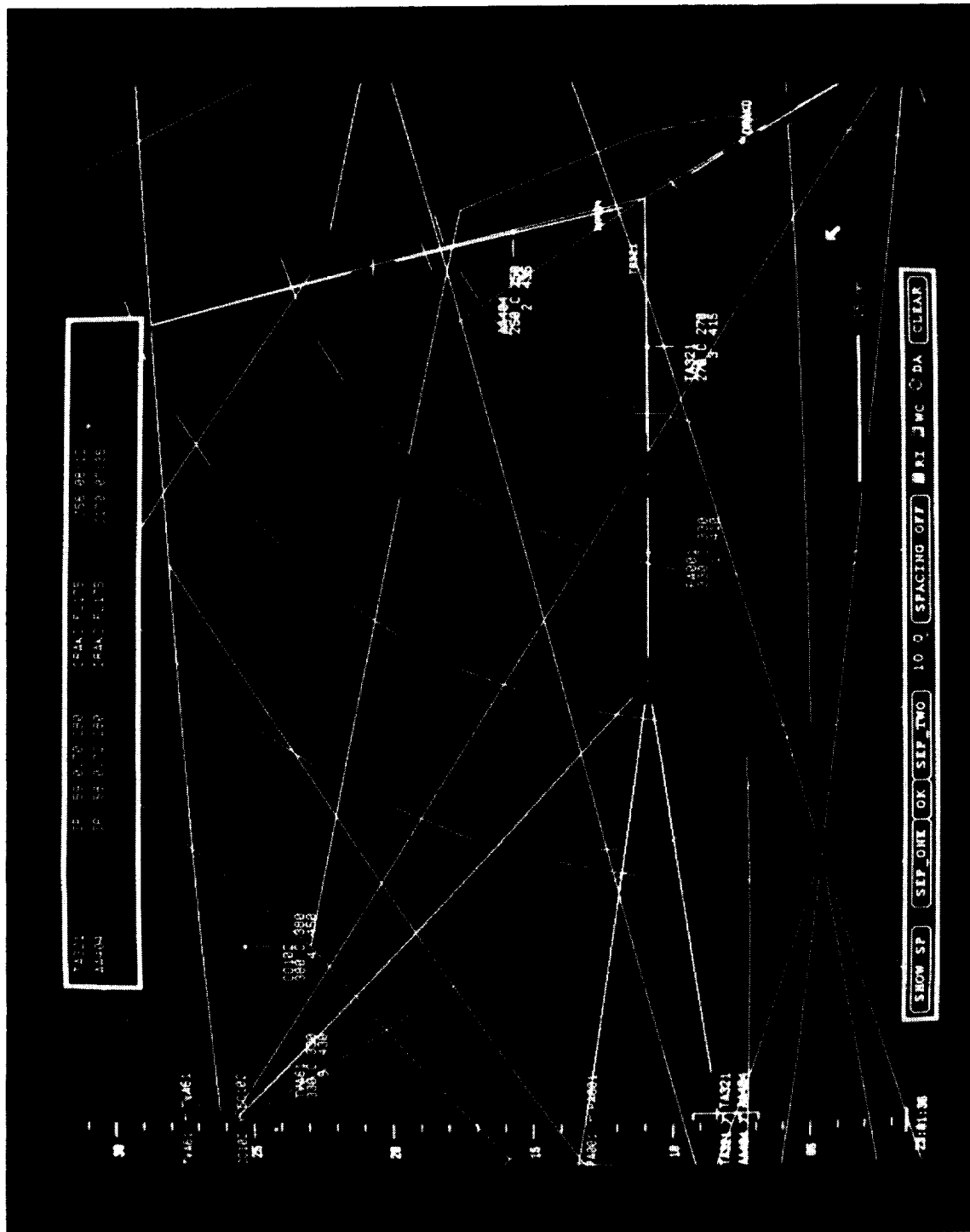
A simulation capability of the Denver TRACON was developed and integrated with the existing Air Route Traffic Control Center (ARTCC) simulation facility. Several major components of FAST have been completed. These include a trajectory synthesis algorithm that makes predictions of aircraft arrival times based on aircraft performance and weather conditions, off-route vectoring advisory capability, rescheduling for arrival position shifts within the TRACON, missed approach advisory capability, an interactive controller graphical interface, a graphical timeline for display of arrival sequence, and communications links and protocols to the traffic manager and ARTCC controller displays. FAST has been implemented to fully utilize the mouse and graphical display output capabilities made possible by the advent of high-powered computer graphics workstations to allow uninhibited communication between the controller and the automation tools. The tool was integrated with the Traffic Management Advisor and Descent Advisor Tools in the March 1989 simulation and shown to be an effective aid for the TRACON controller. The controllers were enthusiastic in their support of the concept and rated the system favorably.

Development of a TRACON simulation greatly enhances the advanced air traffic control simulation capability. It allows the test and evaluation of controller automation aids for the TRACON. It also allows the effects of automation tools designed for the ARTCC (descent advisor) and Traffic Manager on TRACON operations to be evaluated.

A follow-on simulation is scheduled for July 1989. This simulation will include LaRC's 4-D equipped Transport Systems Research Vehicle (TSRV) Simulator. Further development of FAST will include the capability for advisory information on missed approaches and enhanced graphical presentation of advisories. Live traffic evaluations are being planned for 1991.

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Traffic Descent Advisor Display



Airborne Doppler Radar Detection of Microburst Wind Shear Microburst/Clutter/Radar Simulation Program

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The objective of this research was to develop airborne Doppler radar technology for the detection of low-altitude microburst wind shear and assess its capabilities and limitations as a forward-looking sensor for detecting wind shear during aircraft landing or takeoff. The approach was to develop a microburst/clutter/radar simulation program, which accurately simulates a Doppler radar located in an aircraft that is sensing signal returns from a microburst and airport clutter environment, and to utilize it to evaluate the performance of various airborne radar concepts and signal processing techniques.

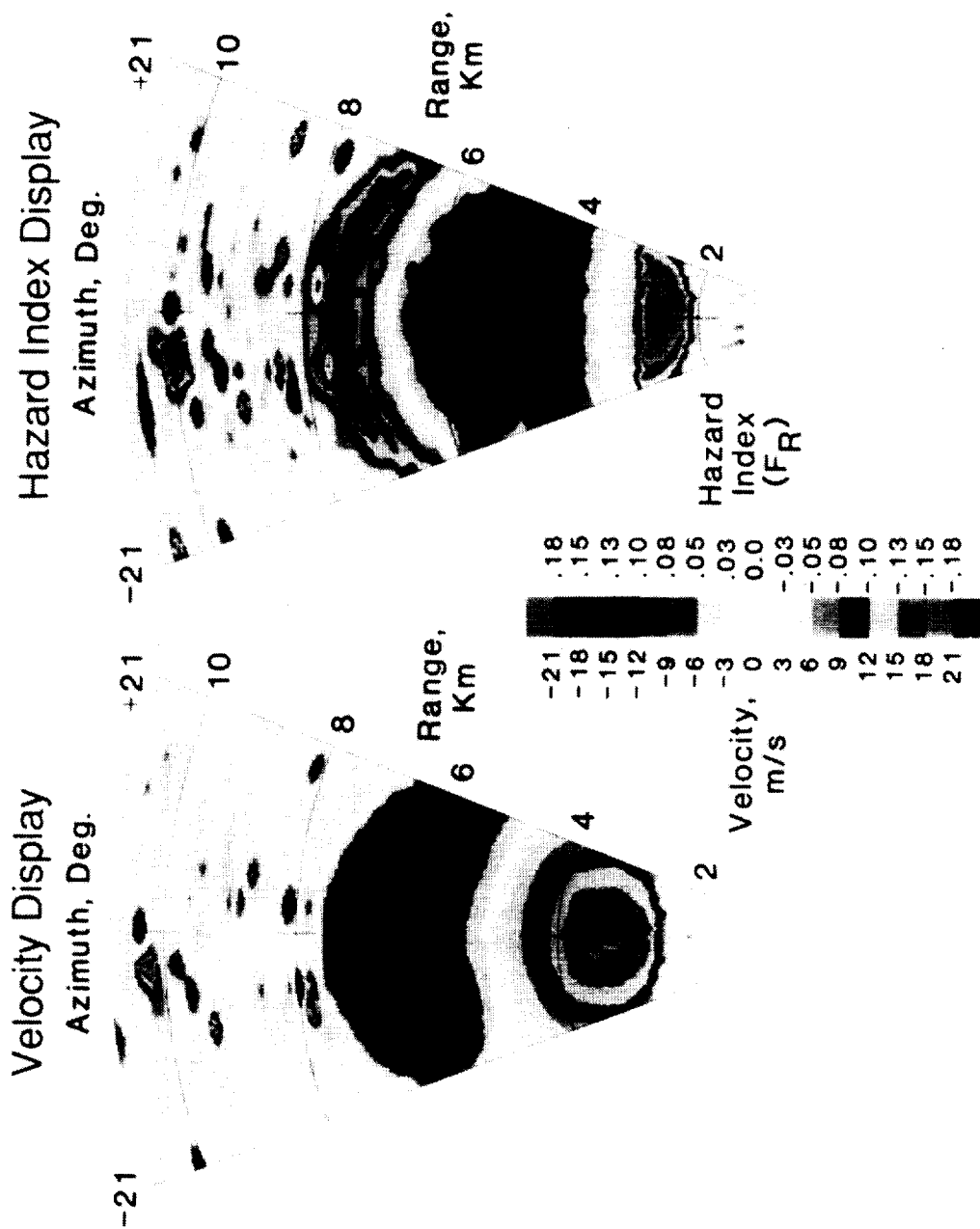
A microburst/clutter/radar simulation program has been developed and utilized in a study to assess the performance of a radar concept sensing both wet and dry microbursts. The results of the study show that wind shear from a wet microburst can be accurately detected 10 sec to 65 sec (0.75 km to 5 km) in front of the aircraft. Output display scans are produced by the simulation, as depicted in the figure; these scans show the performance capability of the radar. The left display shows velocity contours inside a wet microburst with a head-to-tail wind velocity couplet that produces a wind shear of approximately 13 m/sec per km. The right display depicts hazard contours produced by this wind shear with indices greater than 0.08 (a level considered hazardous to aircraft and to be avoided).

These preliminary assessment studies show that Doppler radar has potential as an airborne wind shear detection sensor and that the simulation program can provide an analytical tool for accurately evaluating the performance of airborne radar concepts and signal processing techniques for detecting microburst wind shear during aircraft landing or takeoff.

Future improvements in the program will be made by incorporating more sophisticated signal processing techniques, models to represent moving ground clutter, and methods for evaluating true, nuisance, and missed hazard alarms. A full range of microburst/clutter environments will be investigated, and detailed studies will be conducted to characterize the performance capabilities limitations of Doppler radars to detect dry microbursts.

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Wind Shear Radar



Anomalous Behavior Characterization of Fault-Tolerant Multiprocessor (FTMP)

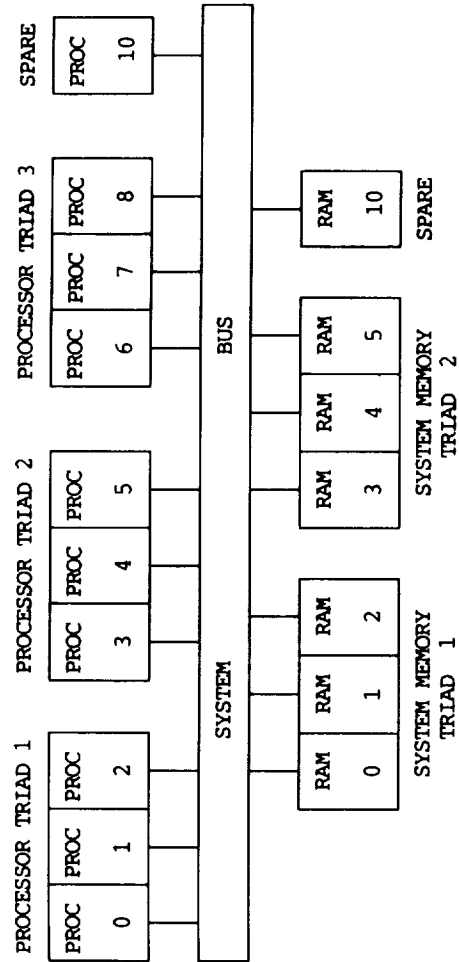
The objective of this research was to characterize the anomalous behavior of the FTMP observed during fault injection experiments. The approach was to perform fault injection experiments in the Avionics Integration Research Laboratory (AIRLAB) on the FTMP to characterize the system's fault-handling behavior and to obtain data for the fault-handling models used in reliability estimation packages. During these experiments, it was observed that the FTMP fault management software repetitively declared faulty and removed nonfaulted Line Replacement Units (LRU's) from the active configuration at an approximate rate of one every 600 faults. Using an in-house designed and built high-speed data acquisition system capable of monitoring the internal communications and state of the system, data were obtained during fault injection experiments that pointed to a design flaw in the FTMP; this flaw allows the fault management software to make an erroneous decision as to the identity of the faulty unit.

The discovered design flaw involves an inefficient design for the system bus communication's hardware and the dependence on nonredundant hardware for error detection and slow-running software to isolate and reconfigure faulty units. Inefficient communication hardware on the system bus increases the time required to read data, specifically the error detection data from each LRU. The long interval between reading individual values of the error data for each LRU allows an error manifestation occurring during the reading process to confuse the fault management software into identifying a good unit as faulty. For example, if the error occurs after the data from the next-to-last LRU has been read but before the data from the last LRU, then although all the LRU's might have detected the error, it appears to the software that only the last LRU's data contain the error detection. All the data from the other LRUs were read before the error occurred; therefore, they did not contain an error detection. A mathematical model of this behavior was developed which allows the probability of the behavior occurring during fault injection experiments and for naturally occurring faults to be estimated. The model's parameters are obtained from fault injection data. In general, the results agree with the experimental data and can be used to predict the observed behavior. Also, by extrapolating the model to a hypothetical triple-redundant fault tolerant system with a similar error-detection subsystem design, it is possible to estimate the system's probability of failure due to the erroneous identification of the faulty LRU. The system fails by losing a good LRU while allowing the faulty LRU to continue operations, thus leaving the system without enough redundancy to mask errors.

This study clearly points out the significance of fault injection experiments on the characterization of the faulted behavior of fault-tolerant systems and the necessary level of detail at which this information must be gathered in order to discover and account for any unexpected results. The information gathered about the details of the FTMP fault management process, its flaws, and weaknesses (using the fault injection technique) cannot be paralleled by simulation or any other design or by the testing tools available at present or expected in the near future. The results highlight the degradation incurred in the fault-tolerant design robustness by using nonredundant hardware for error detection. The technique will be applied to the Fault Tolerant Processor (FTP) in AIRLAB in order to characterize its fault-handling behavior. Preliminary data indicate that the FTP displays abnormal behavior similar to that observed on the FTMP.

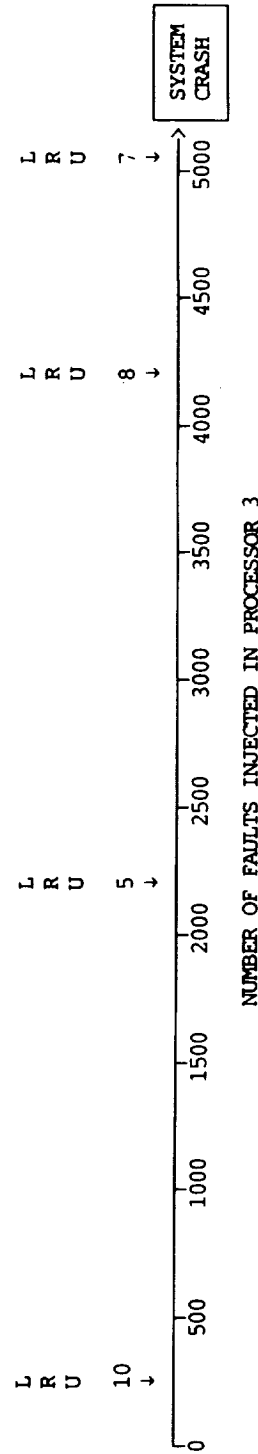
Technical Contact: Peter A. Padilla, LaRC. (804) 864-6187

Anomalous Behavior Characterization of Fault-Tolerant Multiprocessor (FTMP)



(a) FTMP ARCHITECTURE (NOTE: PROC X + RAM X => LRU X)

SEQUENCE OF LRU'S DISABLED (AN LRU INCLUDES BOTH PROCESSOR AND RAM)



Development of Displays for Takeoff Performance Monitoring System (TOPMS)

The research objective of this study was to provide heads-up cockpit displays in which pilots can continuously and effectively monitor their aircraft's performance during a takeoff roll/abort while focusing their primary attention on the visual runway scene. The approach was to build on prior TOPMS research wherein an algorithm to predict/compute pertinent takeoff performance parameters had been formulated and tested in batch simulation. A graphic display to convey this information to the pilot was designed and evaluated on the LaRC Transport System Research Vehicle (TSRV) Simulator. During that research effort, the display was implemented as a heads-down display located well below a real-world pilot's line-of-sight as the pilot looked out the window at the runway scene. A heads-up display (HUD) was selected as the best option to move the TOPMS information close to the takeoff pilot's normal look direction. Further, it was decided that the TOPMS HUD symbology could be simpler than the heads-down version, which was retained concurrently for both pilots.

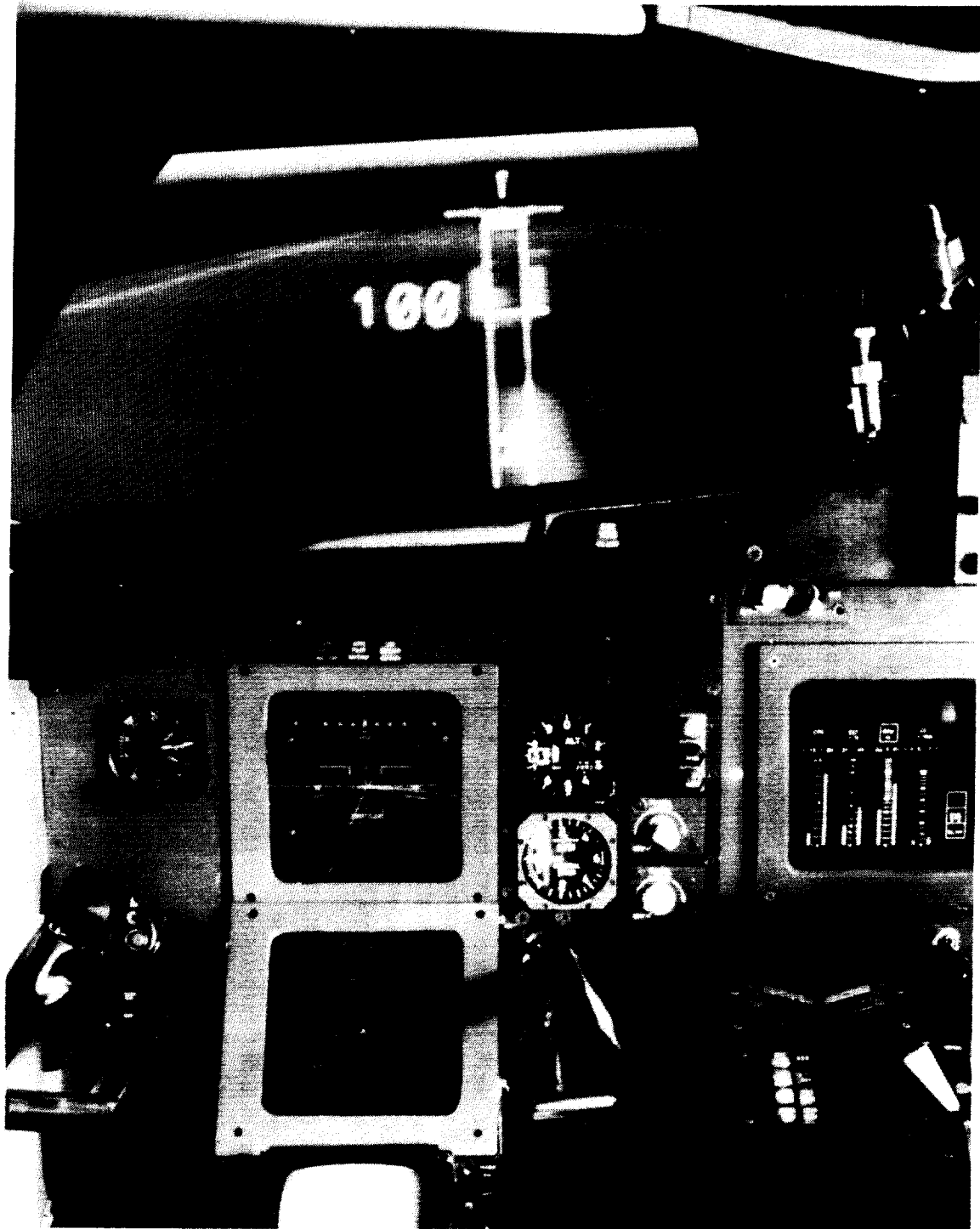
Because the TSRV Simulator did not have a natural out-the-window scene, a video projection of an airport model was used. The TOPMS HUD runway graphic was superimposed and approximately aligned with the projected runway. Seventeen government and industry pilots "flew" and evaluated the combination heads-up/heads-down TOPMS displays for suitability and ease of comprehension. The displays were well received; in particular, the TOPMS HUD was liked because it was proximately available, did not mask out any important visual-scene cues, and provided critical "GO/NO-GO" information where it could not be missed. Several symbology changes have been implemented recently and checked out on the TSRV Simulator but not yet evaluated by pilots. Representative runs with the new symbology have been videotaped.

The TOPMS HUD simulation study provides an indication of the appropriateness of providing real-time airplane performance information in the pilot's viewing area while he is performing the critical takeoff/abort task primarily using visual-scene cues and running knowledge of airspeed. In particular, the TOPMS HUD prominently displays digital airspeed and is strategically positioned to call attention to significant anomalies and/or to advise a course of action.

Future plans for the TOPMS include it being installed as a regular feature on the TSRV and tested in coordination with other flight experiments. The latest symbology changes can then be tested (in conjunction with analysis of the videotapes made on the simulation).

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Takeoff Performance Monitoring System (TOPMS)



ORIGINAL PAGE
BLACK AND WHITE PHOTOGRAPH

Superagility Controls Technology: Tactical Guidance Research and Evaluation System (TGRES)

100

Future fighter aircraft will be superagile, that is, these aircraft will have enhanced agility (maneuverability and controllability combined) throughout the flight envelope. To date, increased levels of agility have been postulated as tactically advantageous, but no capability exists for studying maneuvers that use agility. The objectives of this research are to identify maneuvers that effectively exploit agility and to evaluate the impact of different control laws on the tactical use of agility.

The Tactical Guidance Research and Evaluation System (TGRES) is being constructed to provide a tool for investigating superagility. The TGRES consists of three elements: the Tactical Decision Generator (TDG), the Tactical Maneuver Simulator (TMS), and the Differential Maneuvering Simulator (DMS). The TDG is a knowledge-based system, hosted on a symbolic computer, which generates air combat maneuvering commands based on the tactical status of a one-versus-one engagement ("dogfight"). The TMS is a batch simulation tool for laboratory development and evaluation of rules and scoring algorithms that are implemented in the TDG. The TMS, containing aircraft models and the equations of motion, is hosted on a Micro VAX computer and communicates with the TDG via Ethernet. The DMS enables realistic evaluation of the TDG against pilots in real-time simulation.

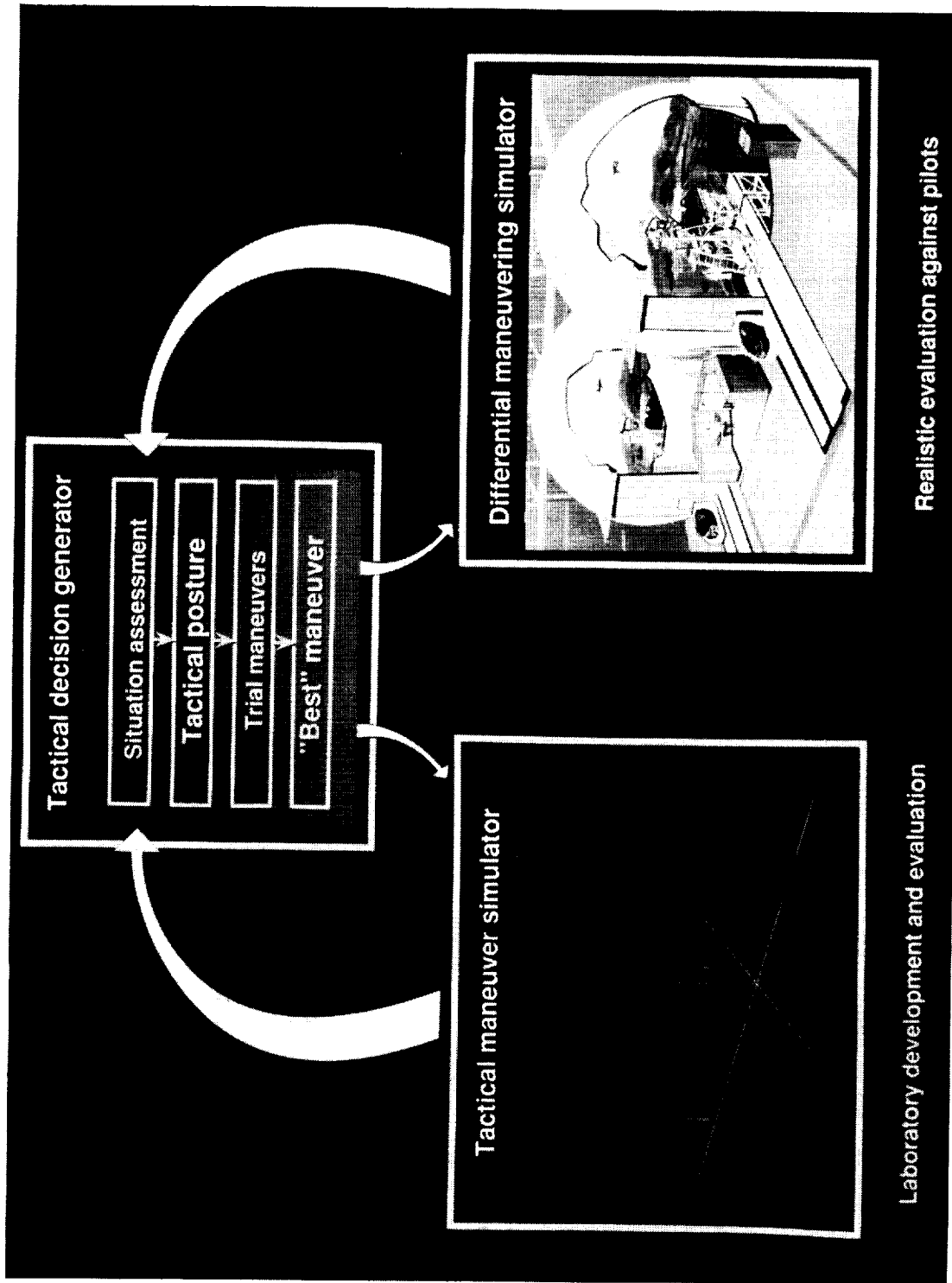
Modern air combat rules and scoring algorithms have been implemented in the TDG. A technique to enable interprocess data transfer between numeric and symbolic computers has been developed. A graphic display showing aircraft trajectories has been defined and implemented for replaying air combat engagements from any orientation. Energy, performance, and weapons parameters for each aircraft are also provided. A situation assessment module has been developed to determine piloting strategies, either aggressive, defensive, neutral, or evasive. An active throttle control based on the current piloting strategy was constructed. A version of the TDG was implemented in the DMS and evaluated against NASA test pilots. The TDG has been evaluated against available versions of Adaptive Maneuvering Logic (AML) and has proved to be superior.

This initial version of the TDG has been used to validate basic concepts and to provide a baseline against which future improvements and new capabilities can be compared. The technique that enables interprocess data transfer between numeric and symbolic computers is a first step toward a real-time TDG interface for both piloted simulation and flight tests. The graphic display promotes a natural, qualitative analysis of the engagement by the engineer/pilot. The situation assessment module and active throttle control allow the TDG to more closely mimic pilot actions, thus improving its realism.

Future plans include replacing the "point mass" aircraft models in the TMS with six-degree-of-freedom models to allow appropriate evaluation of agility dynamics. A two-versus-one engagement capability will be developed to provide tactical realism. New rules and scoring algorithms will be defined that accommodate two-versus-one scenarios and take advantage of enhanced agility, including high-alpha flight conditions. A real-time interface between the DMS and symbolic computer will be implemented.

Technical Contact: P. Douglas Arbuckle, LaRC, (804) 864-4072

Tactical Guidance Research and Evaluation System (TGRES)



Requirements Determined for Flying Complex Paths With Microwave Landing System (MLS) Using Electronic Flight Displays and Advanced Flight Control System

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As part of the joint FAA/NASA MLS Advanced Application Program, one research objective of this work has been to determine guidance requirements for flying jet-transport-type airplanes equipped with electronic flight displays and advanced flight control systems for manually controlled flight along complex, curved paths. A study has been conducted with particular issues addressed that included flight director requirements, electronic map versus standard Horizontal Situation Indicator (HSI) displays, and effects of various path geometries, including length of the final approach segment and consecutive turns.

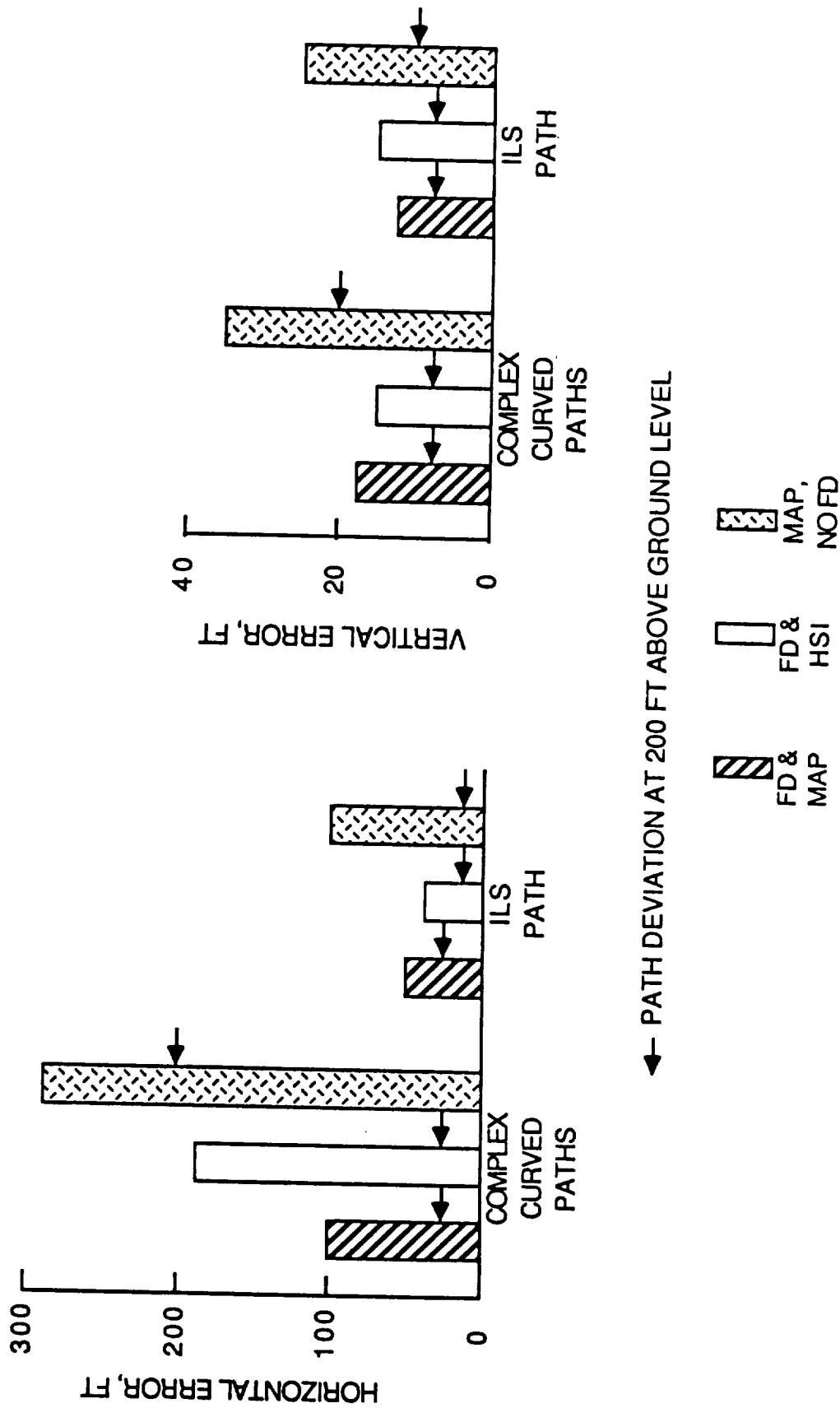
A real-time piloted simulation was used to evaluate three different guidance display options including Flight Director (FD) and map display, FD and HSI display, and map display with no FD. Test runs were made along six complex, curved paths with final approach segments between 1.25 nmi and 0.25 nmi. Runs were also made along a standard Instrument Landing System (ILS) approach so that work load and tracking accuracies between flying complex and conventional straight-in paths could be compared. Airplane state, navigation, control activity data, pilot comments, and pilot instrument scan data were collected. Eight subject pilots (six airline pilots and two NASA pilots) each flew approximately 78 data runs with various wind and moderate turbulence conditions.

Analysis of the path tracking data (shown in the figure) along the complex paths indicates that lateral path tracking performance is slightly improved with the map display versus the HSI display (both using the FD). Tracking accuracy, however, at the decision height (200 ft above the ground where the pilot must land the airplane by looking out the window) is about the same. Vertical tracking accuracy was unaffected by the HSI and map display options. Tracking data indicate that the FD is required for precision complex approach paths with low decision heights. While the tasks were more demanding to fly, even the shortest final approach paths were judged by the subjects to be acceptable with FD guidance. In addition, although pilot work load is slightly higher for the curved paths as compared to the ILS path, the data and pilot comments indicate these operations are acceptable for normal airline operations.

The results of these tests show that airplanes equipped with the proper guidance may be flown on highly complex, curved paths within the MLS signal coverage. This will result in more airplanes attaining the benefits of curved paths including increased airport capacity, safety, and noise abatement capabilities. Additional tests will be performed in the DC-9 simulator with a two-subject crew in an ATC environment to determine the effects of nonstandard operational procedures while flying complex precision flight paths.

Technical Contact: Charles E. Knox, LaRC, (804) 864-2038

Guidance Comparison, Path Tracking Errors (rms)



Controls and Guidance - Space

The Space Controls and Guidance Research and Technology Program is directed toward improving the next generation of space transportation systems and enabling the President's Lunar/Mars Initiative and large future spacecraft and space systems (such as the growth Space Station). Large communication antennas and high-precision segmented reflector telescopes and interferometers will also be considered. The new generation of transportation vehicles has demanding requirements to provide for an order of magnitude reduction in cost as well as an increase in capability. The Lunar/Mars Initiative will have demanding requirements for reliable avionics systems. The future orbital facilities have demanding control requirements for pointing and stabilization, momentum management, build-up and growth accommodation, and disturbance management.

To address advanced launch requirements, research and technology for adaptive guidance is being pursued. A forward-looking laser placed atop the launch vehicle detecting wind velocity provides the data for calculating onboard the desired load alleviation trajectory. This technology has the capability to provide for a large reduction in operations support both in the planning and generation of the mission software and mission control. In support of the Lunar/Mars Initiative, the Advanced Information Processing System (AIPS) forms the basis for our research and technology program into highly reliable fault-tolerant distributed control systems. AIPS along with long-lived reliable avionic system components is an enabling technology to realize the President's Initiative. For complex space systems, computational controls are being developed to provide cost-effective, high-speed, high-fidelity control system simulation and analysis and synthesis tools. The thrust of this work will be to develop methods and software to enable a 4 order-of-magnitude improvement in analysis and real-time hardware-in-the-loop simulation for control design certification. To address future orbital facilities requirements, an advanced technology program is under way in system identification, distributed control, and advanced sensors and actuators. Because the behavior of complex space systems is greatly influenced by the ground environment, thinking is currently being directed toward a Space Station testing and verification facility that also has the potential for enabling innovative research with "structureless" systems.

Program Manager: John D. DiBattista
NASA/OAET/RC
Washington, DC 20546
(202) 453-2743

Autonomous Rendezvous and Docking

Historically, all of NASA's rendezvous and docking operations have involved manned vehicles flown by an onboard pilot. For many currently planned missions, such as the Mars Rover Sample Return (MRSR) Mission, the docking vehicles will be unmanned. Also, the communications-loop time delays involved make teleoperated docking impractical. Therefore, there is a definite requirement for technology to facilitate totally autonomous rendezvous and docking (AR&D).

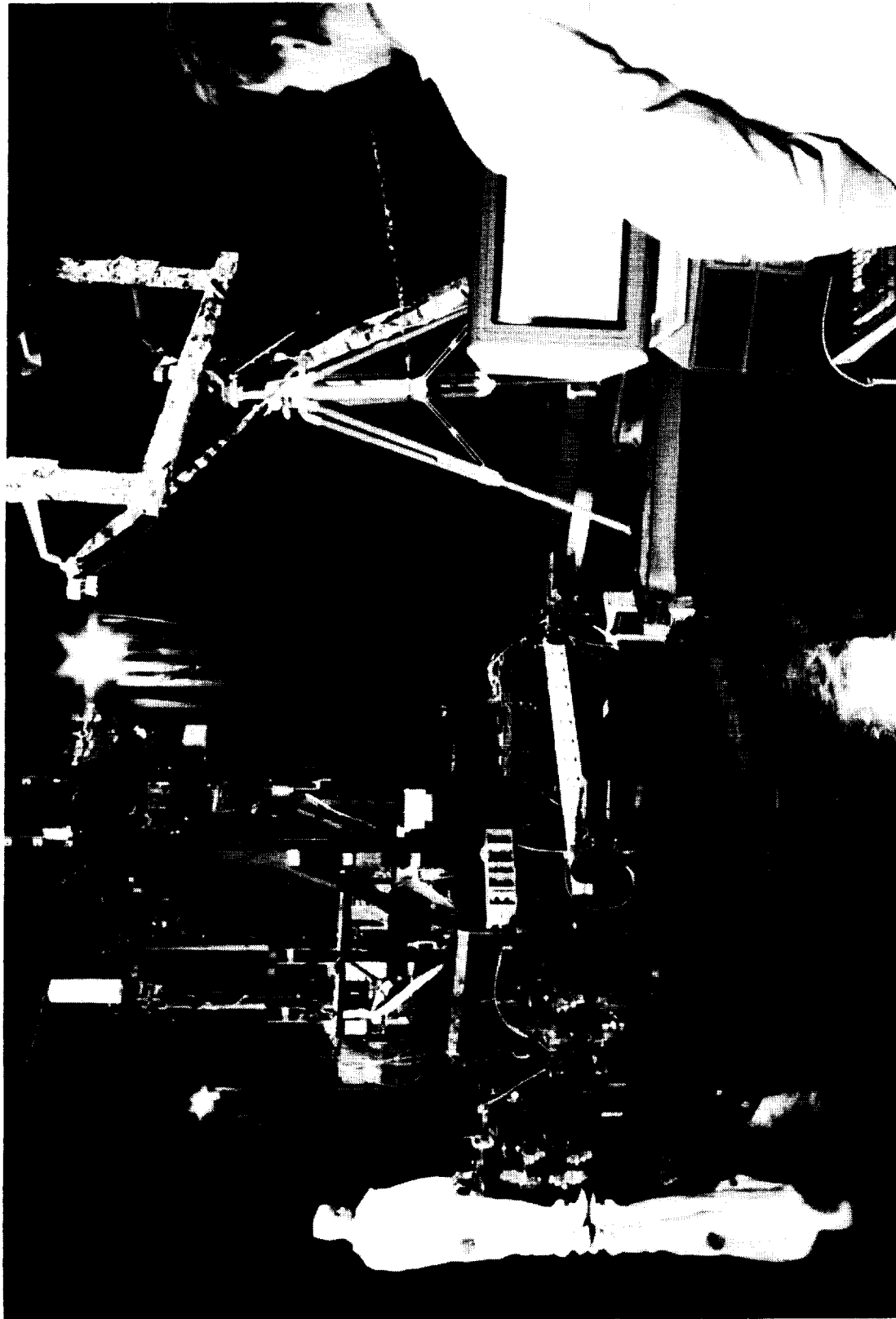
MSFC is currently developing advanced vehicle control algorithms for AR&D which generate thrust commands and attitude adjustments based on inputs from one or more navigation sensors. The goal of this effort is a system having performance (efficiency, speed, and dependability) equal to or greater than that of a human pilot hypothetically flying the same spacecraft. Also, the system will possess redundancy management capabilities to facilitate continued operation in the event of sensor failure or degradation. Power, weight, and volume of the processing hardware are kept to the minimum needed.

During the current fiscal year, MSFC has successfully demonstrated an AR&D system using a full-scale air-bearing simulator. The demo configuration included a six-degree-of-freedom phase-plane control system, a laser-illuminated video navigation sensor, and an 80386/80387 computer. Docks were successfully made from a variety of initial attitudes and positions.

The current goals of this effort include the development of higher performance more adaptable control algorithms and the test of these algorithms under more demanding conditions. A cooperative effort has been initiated with ARC to develop neural network based pattern recognition and control algorithms. The ultimate goal is the development of a system capable of docking with a potentially tumbling target under worst-case conditions, suitable for use in a variety of missions.

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Richard Howard, MSFC, (205) 544-3536

Autonomous Rendezvous and Docking on MSFC Flat Floor



ORIGINAL PAGE
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Lunar/Mars Autonomous Lander Hazard Detection

The objective of this program is to examine the use of vision-based methods to detect surface hazards in the landing phase of an autonomous lander. The program will build on similar research being conducted to detect hazards during helicopter low-altitude flight and landing.

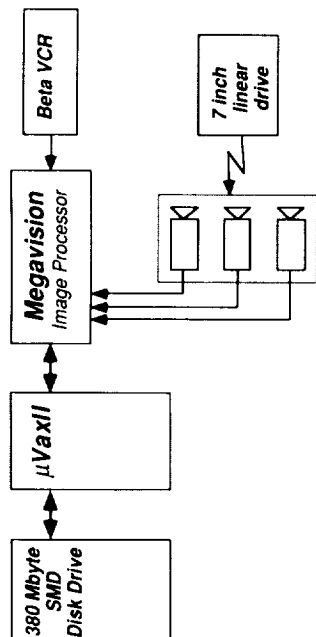
The autonomous lander hazard detection problem is viewed as a problem of determining shape from motion of the sensors augmented by stereoscopic imagery and other vision-processing techniques as deemed appropriate. Two approaches, field-based and feature-based, have been examined for recovering range from motion. Field-based algorithms perform range estimation for every point in the image by studying the intensity variation analytically over time. They have the potential of providing a complete map of the hazards in the field of view. However, the computational experience with natural images using this approach is limited. Currently, two different algorithms are being used to get a better understanding of the computational issues. The first is a feedback solution to the image irradiance equation, and the second is velocity filtering. Feature-based algorithms identify and relate features in successive frames through correlation. A Kalman filter based recursive-estimation technique to get range information using a sequence of images has been developed.

Both the field-based and feature-based approaches will require augmentation by other methods such as shape from shadows, shape from shading, or texture analysis. An amendment to an existing contract with Honeywell is being negotiated to investigate augmentation of the basic shape from motion algorithms with these other methods to provide a reliable hazard detection algorithm for the landing phase.

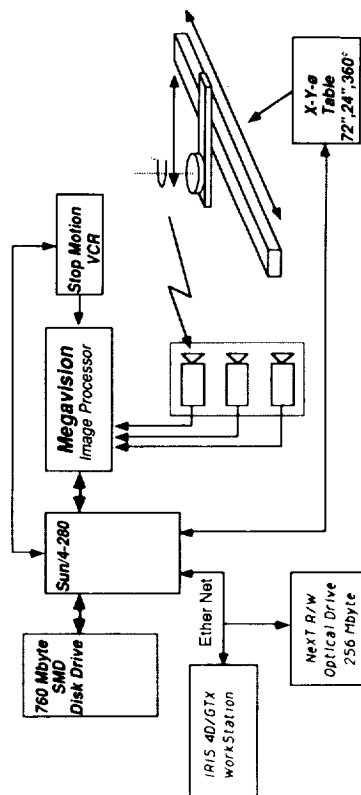
During the next year, the integration of these methods will be initiated. The effectiveness of the algorithms will also be examined using images from simulated Mars scenarios generated by JPL.

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Victor Cheng, ARC, (415) 604-5424

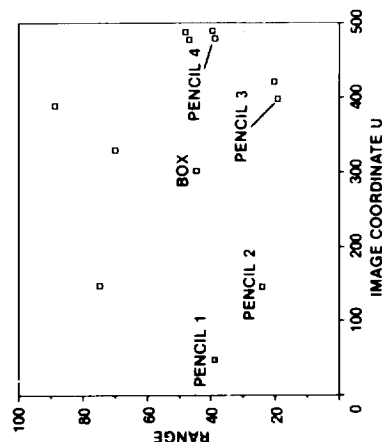
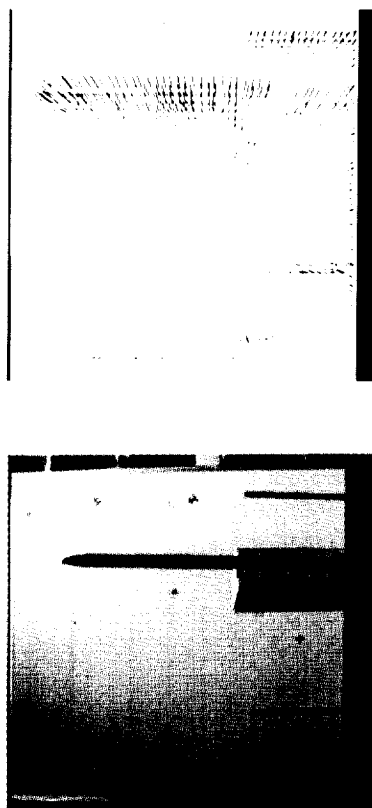
CURRENT LABORATORY CONFIGURATION



FUTURE LABORATORY CONFIGURATION



VALIDATION OF FEATURE BASED METHODS FOR CONTROLLED DATA SET



Guidance, Navigation, and Control of Future Aeromaneuvering Vehicles

Many future space missions are enabled or enhanced by the use of aerodynamic forces at hypersonic speeds to modify a space vehicle's trajectory. Mission applications of this type include aerocapture into a bound orbit about the Earth or another planet, aerobraking to reduce the size and eccentricity of an elliptical orbit, synergetic plane changes using both propulsive and aerodynamic forces, and descent from orbit to a planetary surface. In each case the efficient use of a planetary atmosphere can substantially reduce propellant requirements and mission costs.

The benefits of aerobraking and aeromaneuvering can be achieved only if a space vehicle's trajectory can be controlled to a high degree of accuracy as the vehicle passes through the atmosphere. This is made difficult by the fact that the atmospheric density and vehicle aerodynamic properties are not known sufficiently well in advance, and that entry conditions cannot be controlled precisely. The onboard guidance, navigation, and control subsystem must then be able to determine in real time the true flight environment and quickly adapt to that environment. In many applications, the required guidance and navigation computations cannot be performed on the ground due to round-trip light time or communications blackout considerations.

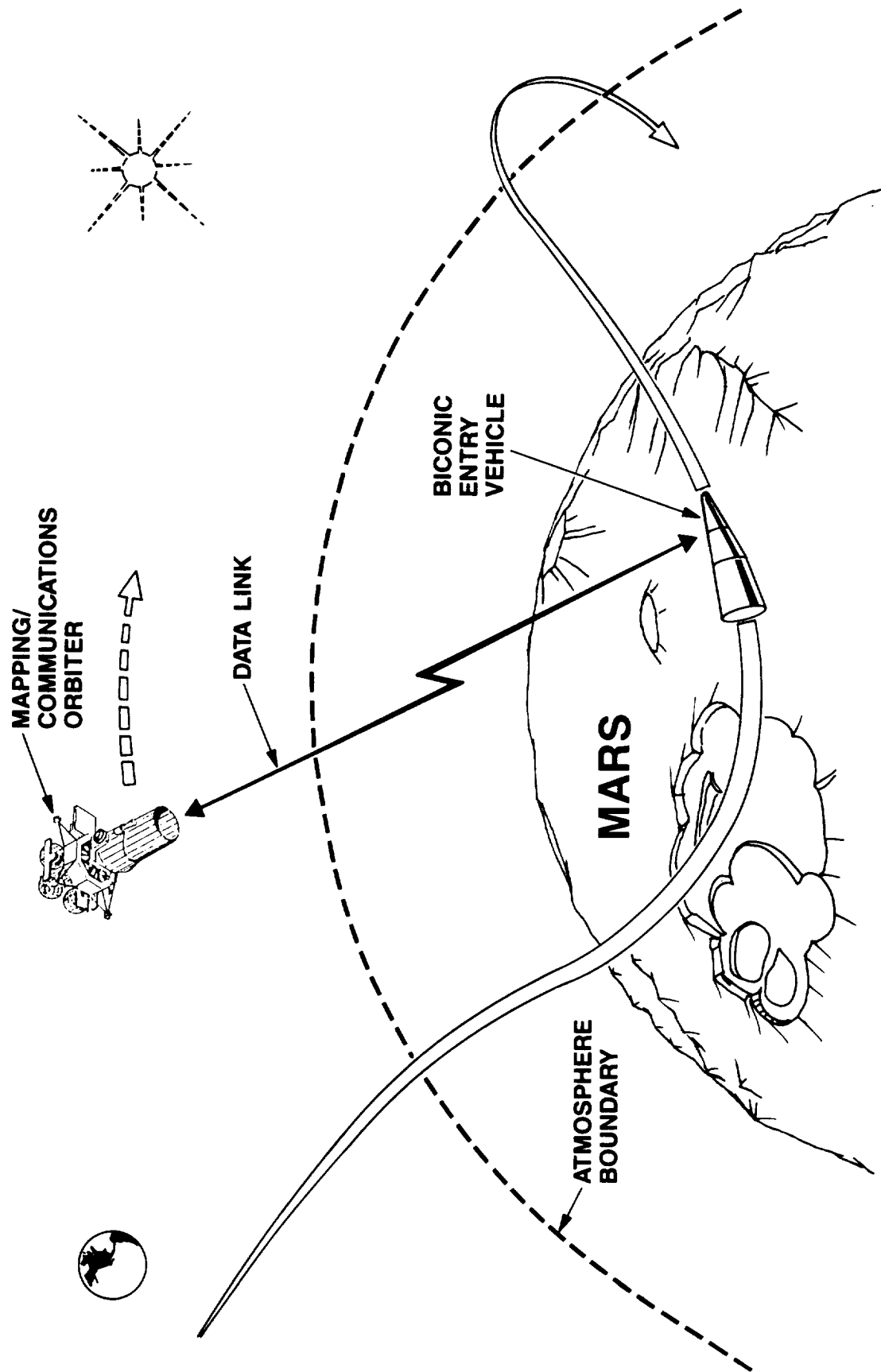
For several years, work has been under way at JPL designing atmospheric trajectories that minimize propellant consumption while also minimizing such vehicle design drivers as maximum heating rate, total heat input, and maximum acceleration. Autonomous, onboard, fault-tolerant guidance, navigation, and control algorithms that accurately control atmospheric exit or landing conditions have also been under development.

During the past year, in-house efforts have included assessing the effects of navigation and guidance errors on entry and landing accuracies for several vehicle configurations in unmanned and piloted missions to Mars. The guidance and navigation schemes being investigated produce much more accurate landings than were achieved in the Viking mission. A closed-loop, onboard guidance algorithm for near-optimal control of four state variables at atmospheric exit has been developed for general coplanar and noncoplanar orbit transfer applications. Three-dimensional attitude-control simulation software with orbit plane change capability has been developed.

Work on optimal orbit transfers, particularly synergetic plane changes, has been performed under contract at the University of Michigan, the University of Texas at Austin, and Rice University. An algorithm has been developed for determining optimal plane change trajectories using multiple atmospheric passes. Aeroglide and constant-altitude aerocruise trajectories have been shown to produce nearly equivalent fuel savings for plane changes between circular orbits. Different objective functions have been compared for use in aeromaneuvering optimal control problems. Necessary conditions for achieving minimum-fuel, two-impulse, aeroassisted transfer trajectories between arbitrary elliptical orbits have been deduced.

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Guidance, Navigation, and Control of Future Aeromaneuvering Vehicles



Robust Multipoint Boundary Value Problem Solver

The objective of this research is to develop and evaluate a software tool to provide an extremely convergent means of solving Multipoint Boundary Value Problems (MPBVPs) that arise in optimal control and trajectory optimization.

The core of this tool is a Finite Difference (FD) MPBVP solver whose structure is specialized to the needs of control theoreticians. The FD code is small, simple, and efficient, and relies on a MACSYMA-based front end for supplying nodal error Jacobians, rather than numerical differentiation. The code has convenient "hooks" for treating boundary-layer effects, state and control inequality constraints, and interior boundary conditions.

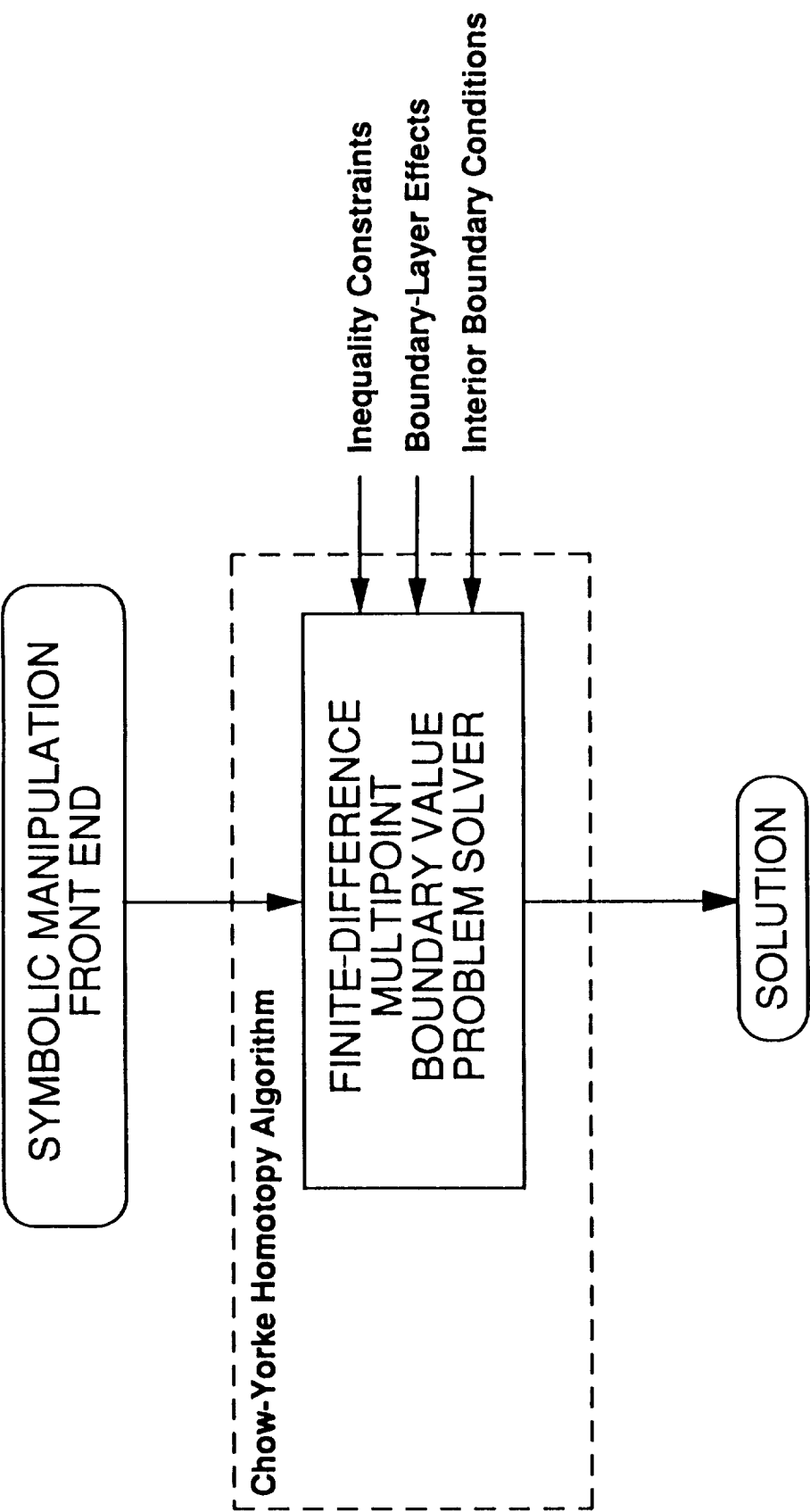
A first revision of this code has been completed and validated, and is in research use at the LaRC Spacecraft Controls Branch.

A number of external organizations have expressed an interest in the code. A user manual is being prepared before the software is released.

Although finite-difference methods exhibit considerably more robust convergence than, for example, multiple shooting, situations still arise in which an adequate initial guess for a solution is difficult to obtain. For this contingency, the FD code is being embedded into an adaptation of the Chow-Yorke homotopy algorithm for the solution of fixed point problems. This algorithm is based on Sard's theorem from differential geometry and assures global convergence to a solution. Since the core representation of the MPBVP will be embedded in the FD code, the user interface is still straightforward and transparent.

Technical Contact: Daniel D. Moerder, LaRC, (804) 864-6495

Robust Multipoint Boundary Value Problem Solver



Stochastic Feedforward/Feedback Guidance

The objective of this research is to develop and evaluate advanced guidance algorithms for application to future transportation systems such as aeromaneuvering spacecraft.

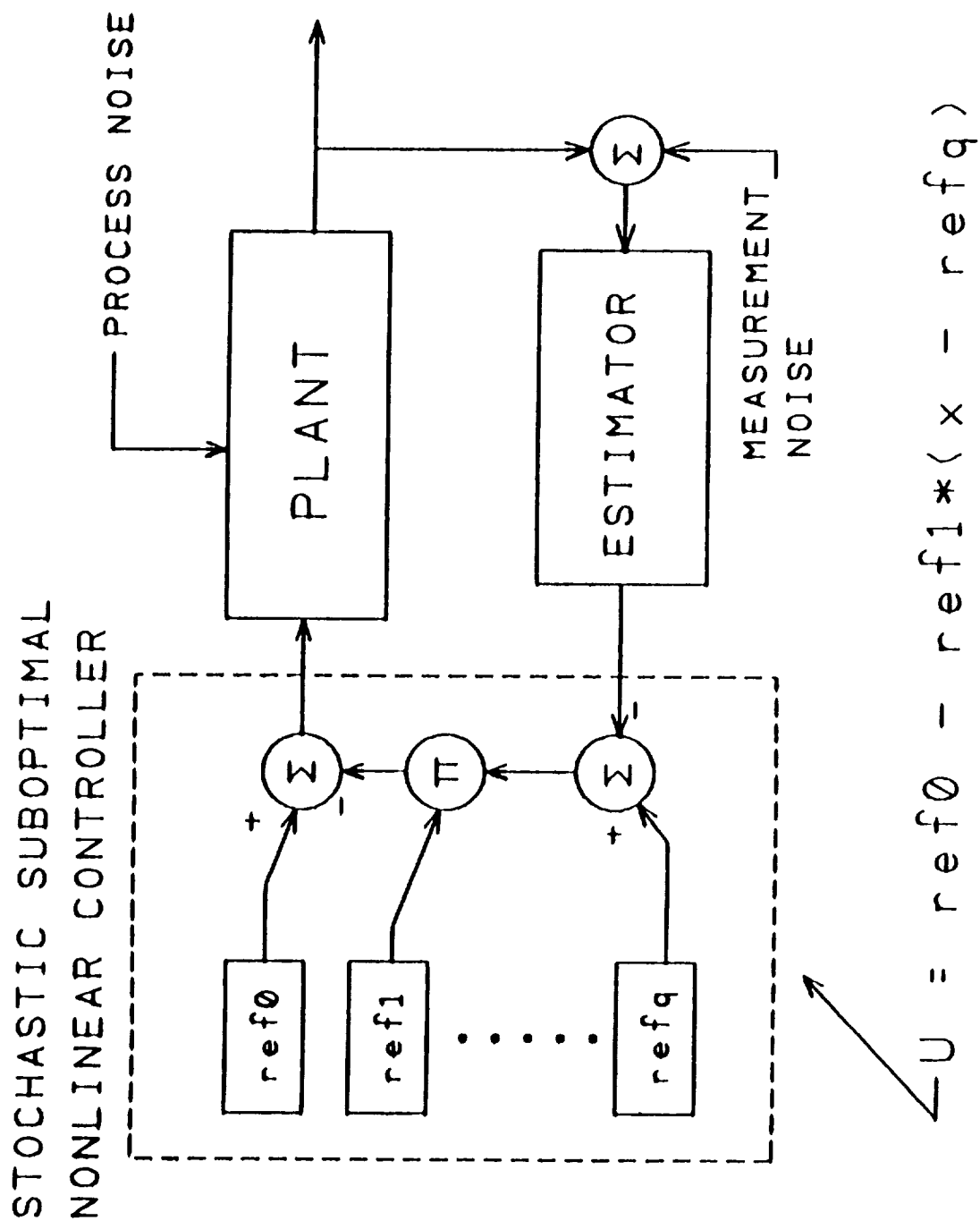
Stochastic Feedforward/Feedback Guidance (SFG) is a novel approach to obtaining high-performance nonlinear feedback trajectory shaping. The SFG directly accommodates a stochastic plant description and a cost function expressed in terms of expectation quantities. Boundary conditions are imposed on the mean and covariance of the plant trajectory rather than on the trajectory itself. This approach allows the formulation of the guidance problem so that typical statistical mission requirements (such as "3-sigma" dispersion limits) are directly met.

Although the theory is generic, the motivation and current application area is that of guidance for aeromaneuvering spacecraft. In an SFG control law synthesis, the control variables are predefined to satisfy structural constraints which imply error feedback in tracking an exogenous feedforward signal. The mean and covariance propagation expressions for the plant are then derived in discrete time, and the boundary value problem arising from the application of the Minimum Principle of optimal control is solved. The resulting simple controller will meet the statistical requirements imposed by the cost function and boundary conditions.

The main challenge in developing this technique is that of solving the Multipoint Boundary Value Problems (MPBVPs) which provide the control solution. This is attributed to the relatively high state dimension of SFG problem formulations. The Robust MPBVP solver research previously reported is an integral and central part to the success of this activity.

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Stochastic Feedforward/Feedback Guidance



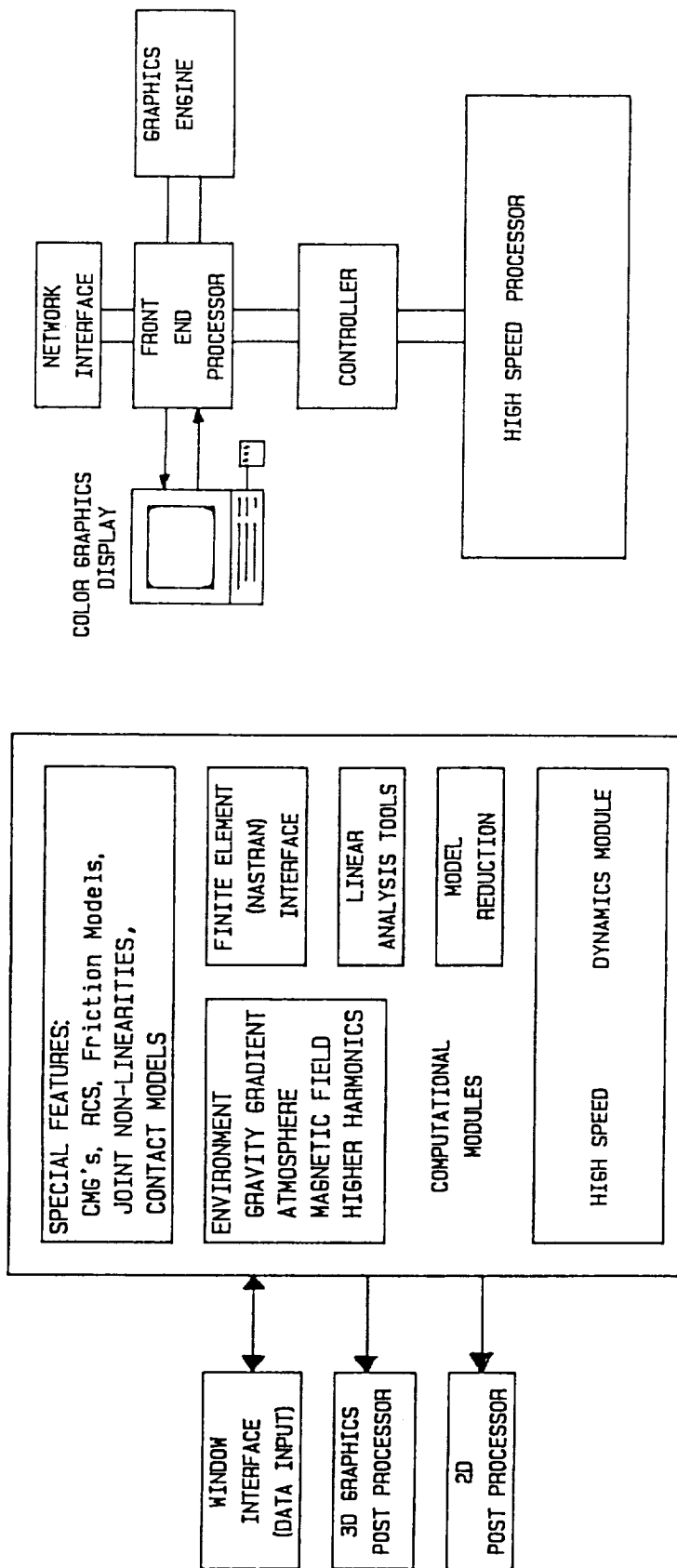
Computational Control

The objective of Computational Control is to design and optimize highly efficient computational algorithms for the solution of multiflexible body dynamics problems. These highly efficient computational algorithms are combined with specialized parallel-processing architectures that have been tuned to this application.

The JSC has teamed with the LaRC to develop and apply Computational Control technology. The order n solution algorithm for multiflexible body dynamics will be used as a starting point, and a parallel version of this algorithm will be developed. Issues to be addressed include load balancing, data dependency paths, and dependence on system topology. Parallel-processing architectures that mesh with the solution algorithm will be examined.

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Computational Control



Hardware Structure.

Software Structure.

Computational Control - Real-Time Testing

Development of complex spacecraft required for future missions will demand control-system analysis and test capabilities that are currently unavailable. In order to design and test such control systems, designers will need to model very high-order linear and nonlinear dynamic systems involving 500-2000 system states. They will need to compute robust, optimal control systems for these models, conduct performance verification simulation, and support system identification and anomaly investigation during mission operations.

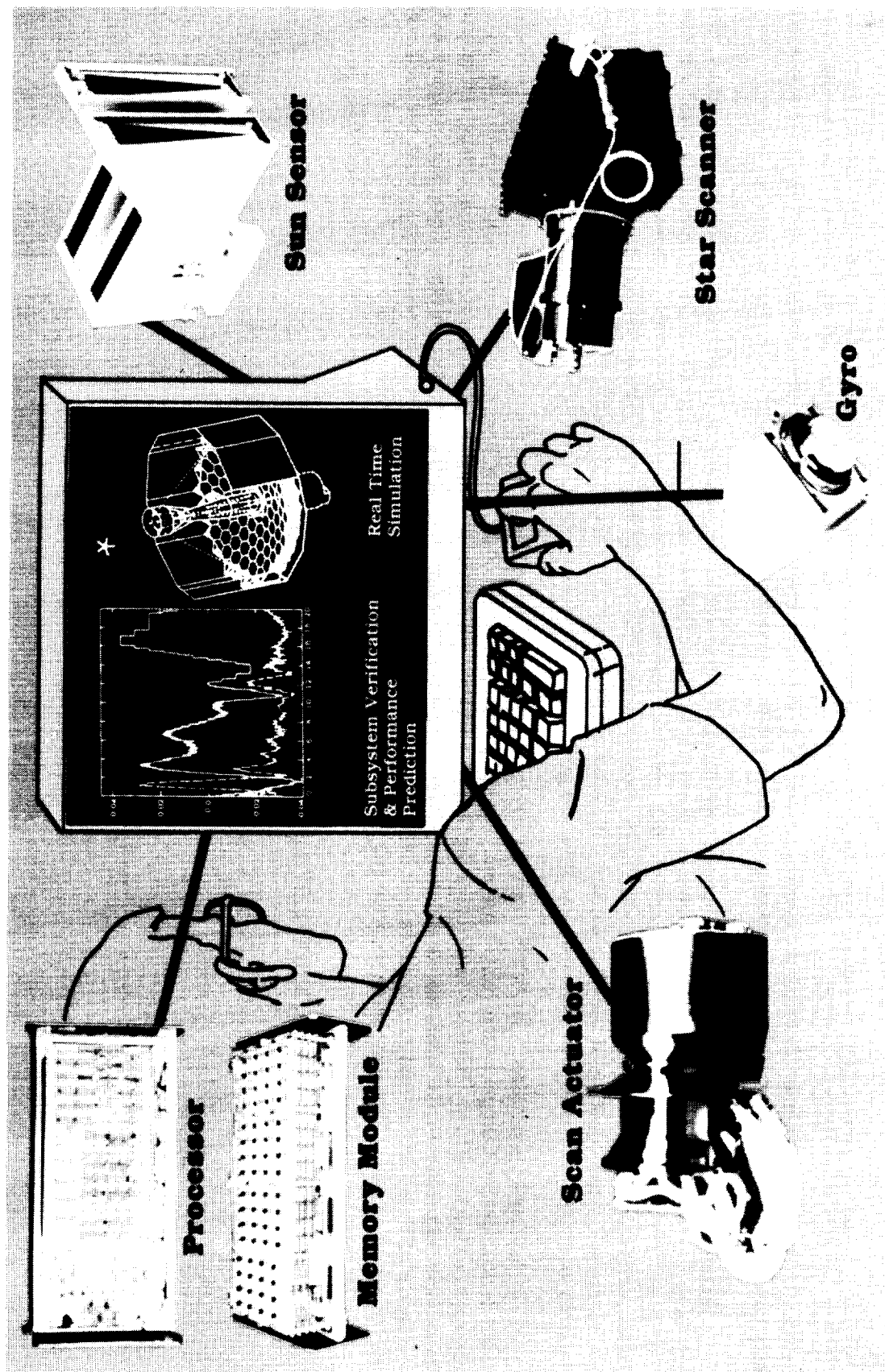
The objective of this program is to develop new generation articulated multibody spacecraft modeling and to control design and simulation software tools in order to achieve a four orders-of-magnitude improvement over current capabilities to enable space missions in the mid-1990s and beyond.

These challenges can be met by developing advanced numerical techniques and algorithms, including spatially recursive algorithms, automatic component representation preprocessors, parallel computing algorithms, and AI symbolic manipulation preprocessors. The need for rapid response can be fulfilled by developing visualization methods for time dependent data display, for system synthesis and model verification, and numerical methods for real-time hardware-in-the-loop simulation.

The principal accomplishments of fiscal year 1989 have been the completion of a technical program plan, of a first draft user-requirement document, and of a detailed study cumulative survey of rigid multibody dynamic algorithms. A national conference also has been planned. The multicenter technical program plan was reviewed by the Advisory Committee and by all participating centers. A first draft of the user requirement document includes reference problems and software functional and performance requirements. One hundred and ten technical papers will be presented at the Oxnard Conference with many breakthrough papers in parallel computing, real-time simulation, and model reduction. The detailed study cumulative survey of algorithms for rigid multibody dynamics of serial chains and serial and parallel computational issues reveal important findings of the numerical efficiency at rigid-body formulations. This work will be expanded to the flexible-body problems for fiscal year 1990.

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Computational Control - Next Generation Subsystem Real-Time Testing



Advanced Control Evaluation for Structures (ACES)

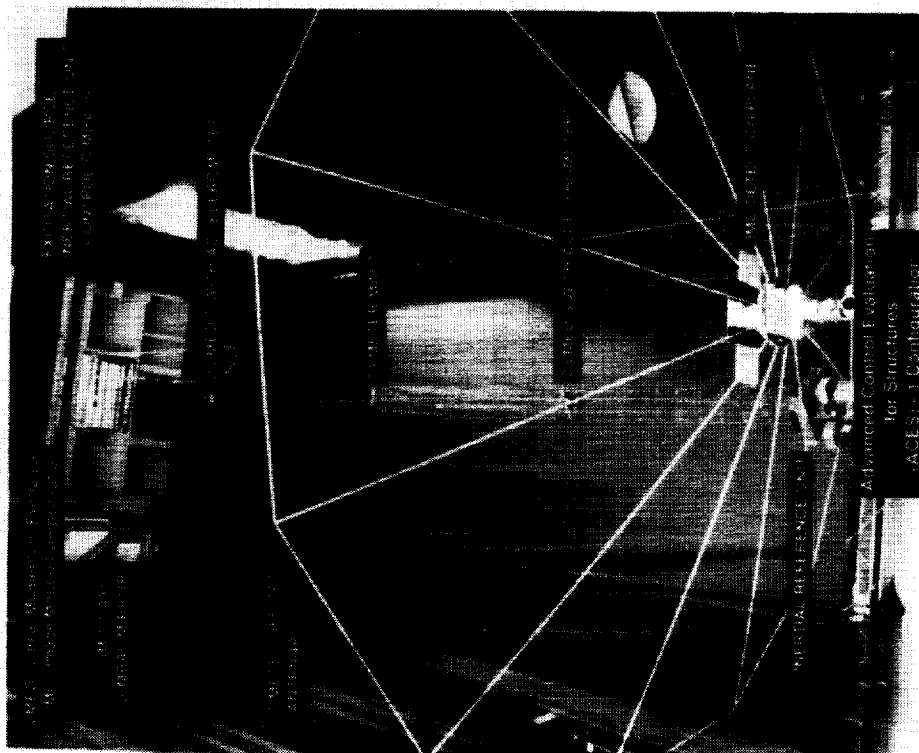
The objective of the ACES program is to effect a control system methodology for future NASA projects that have closed-loop constraints. The closed-loop performance constraints can stem from pointing, tracking, and isolation requirements for vehicles, spacecraft, and space systems. To effect the control methodology for these systems, ground facilities, called ACES, have been and are being constructed where advanced control methods can be developed, tested, and verified.

Many of the advanced control techniques are very attractive relative to the analytical literature capabilities. In contrast, the path from the literature to hardware implementation is usually long and tedious with many iterations before a control synthesis can be effected. The ACES programs are formulated so that advanced control concepts on complex hardware systems, which have similar system pathologies as an actual NASA space system, can be evaluated. The ACES-I program has demonstrated its utility in evaluating four advanced control concepts in the time domain. To completely evaluate any control concept, tasks such as time response analysis, frequency response analysis, robustness analysis, failure analysis, and algorithm implementation must be performed.

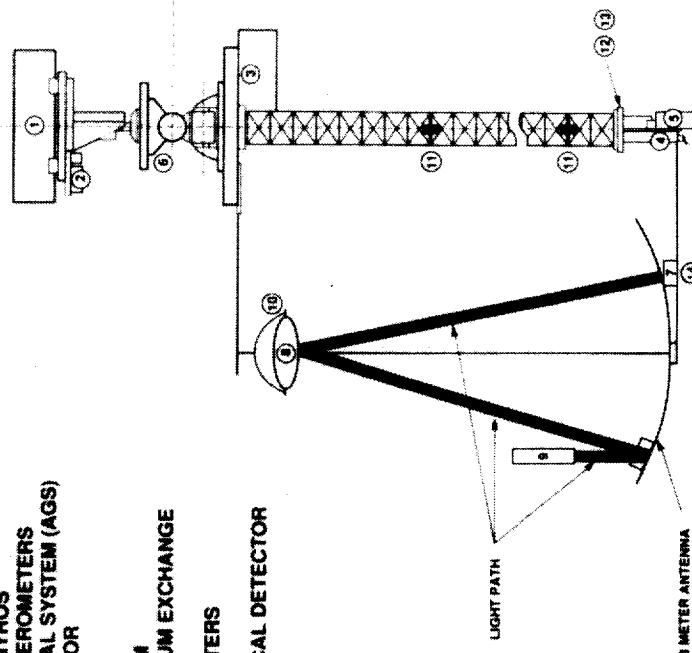
To facilitate these tasks, the ACES-I test facility has been expanded to include a Laser Motion Optical Detector (LaMOD) for the Image Motion Compensation (IMC) system. The control computer capability has been enhanced by incorporation of an array processor in the closed loop. With the addition of the LaMOD to the IMC system, frequency analysis, robustness analysis, and failure analysis can be performed for advanced control concepts. With the incorporation of an array processor in the closed loop, an increase, by a factor of three in the control algorithm size can be achieved. These two hardware changes were necessary so that the ACES-II program could proceed. The completion date for the ACES-II program was scheduled for December 1989.

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Future ACES Configurations



1. SHAKE TABLE
2. 3 AXIS BASE ACCELEROMETERS
3. 3 AXIS BASE RATE GYROS
4. 3 AXIS TIP RATE GYROS
5. 3 AXIS TIP ACCELEROMETERS
6. ADVANCED GIMBAL SYSTEM (AGS)
7. OPTICAL DETECTOR
8. REFLECTORS
9. LASER
10. 2 GIMBAL SYSTEM
11. LINEAR MOMENTUM EXCHANGE DEVICE (LMED)
12. BILINEAR THRUSTERS
13. ROLL TIP MOTOR
14. ENLARGED OPTICAL DETECTOR (15X15 INCH)



Spacecraft Control Laboratory Experiment (SCOLE) Attitude Measurement System

The objective of this program is to develop and evaluate a three-axis attitude measurement system for the Spacecraft Control Laboratory Experiment (SCOLE) that would permit the investigation of advanced control concepts for the simultaneous maneuvering and vibration suppression associated with large flexible spacecraft.

The use of camera detectors and Light Emitting Diode (LED) targets provides a noninertial sensing device that extracts the attitude parameters directly from the measurements. The unique LED configuration provides a significant simplification of the nonlinear transformation equations, resulting in reduced computational burdens. Momentary loss of signal or signal corruption does not affect the tracking process. These features are of extreme importance in real-time attitude computations.

A three-axis measurement system, composed of a pair of cameras, LEDs mounted on the spacecraft model, and the attendant software, has been developed. The algorithm utilizes camera position information of the three LEDs, permitting arbitrary camera placement and on-line attitude extraction. The isosceles-triangle LED configuration reduces the complexity of the nonlinear rigid-body transformation equations, permitting a closed-form solution. The continuous nature of the algorithm allows identification of camera placement with respect to some initial position of the three reference LEDs, followed by on-line six degree-of-freedom attitude tracking.

The camera and LED systems have been developed and installed. The general mathematical formulation of the algorithm has been finalized. Camera position identification and rigid-body maneuver tracking have been tested on a reduced size SCOLE-like model. Experiments revealed global linearity error as low as 1 to 2 percent. The performance of this system will be tested on the SCOLE apparatus. Expected increases in environmental noise and detector nonlinearities will be dealt with by increasing the output of the LEDs and using lower system amplifier gains. Further study of the sensitivity of the attitude angles displacements to system parameter variation will be conducted.

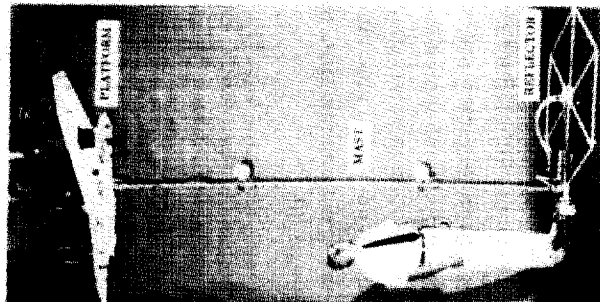
Technical Contact: Joram Shenhar, LaRC, (804) 864-6617

Spacecraft Control Laboratory Experiment (SCOLE) Attitude Tracking System

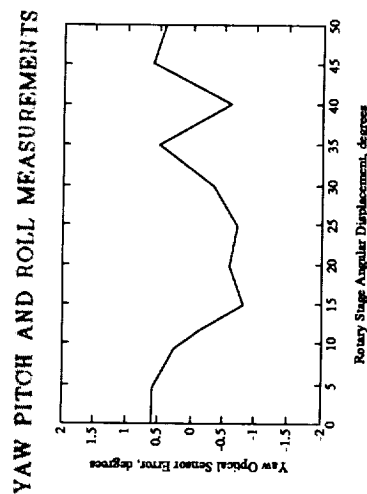
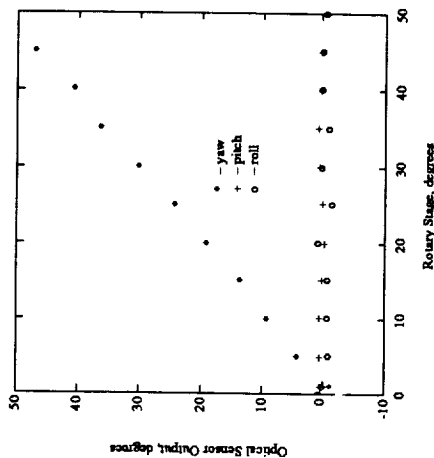
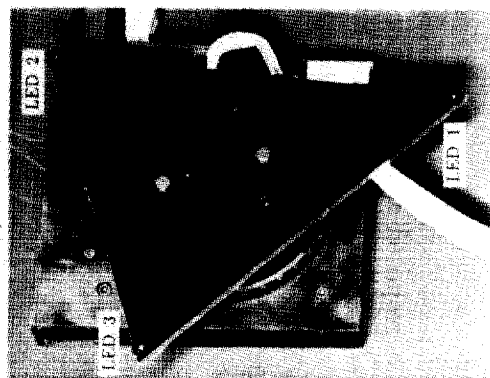
SIGNIFICANCE

- * Camera-LED system provides a sensing device that extracts attitude parameters directly from the measurements
- * Simplified transformation equations
- * Reduced computation effort

THE SCOLE APPARATUS



SCOLE-LIKE LABORATORY MODEL



YAW ERROR - LESS THAN 2%

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Control Technology Validation

The objective of this effort is to demonstrate new evolving and critical methodologies associated with the active control of large flexible space systems. Extensive research has been conducted over the past decade by JPL and other research organizations in the sensing, parameter identification, and control of large flexible structures, motivated by the proposed space applications of large communication and radiometry antennas, reflectors for astronomy and space defense, and large multiple payload platforms. Experimental validation of these methodologies establishes performance levels in the presence of model errors, nonlinearities, unmodeled sensor and actuator dynamics, and problems associated with discrete implementation including sampling effects and phase delays. Demonstration of new methodologies on a ground experiment is crucial to their eventual acceptance in flight systems. By providing quantitative evaluation of critical technologies, experimental structure evaluation significantly advances the state of the art in the control of large flexible space systems.

In response to the needs for experimental evaluation of control methodologies, JPL, in a joint activity with the Air Force Astronautics Laboratory (AFAL), developed this ground-based large flexible structure, which forms the base for the Large Spacecraft Control Laboratory (LSCL). The experimental structure resembles a large space antenna, with 12 flexible ribs, a central hub, a flexible boom, and a tip mass simulating a feed. A suspension system consisting of 24 weights hung over 24 low-friction pulleys provides support against gravity. The overall diameter of the structure is 18.5 ft. Design goals that were successfully achieved include densely packed normal modes, low frequencies, light structural damping, and three-dimensional structural coupling. Included in the facility are 30 sensors, 14 actuators, and a control computer to provide real-time and batch processing. The facility is also integrated with the SHAPES sensor, a remote electro-optical sensor that provides up to 15 additional position measurements.

The LSCL facility has been in full operation since 1987. Past accomplishments include the completion and documentation of the Phase I experiments in Adaptive Control, Unified Modeling and Control Design, Static Figure Determination, and Computer Vision for Shape Verification. More recent accomplishments include the completion of the second Adaptive Control experiment, the Nonparametric System Identification experiment, and the first joint Caltech and JPL Robust Control experiment. In addition to the JPL base research and technology experimental validation effort, a university/industry Guest Investigator (GI) program under joint sponsorship with AFAL has been initiated. Four institutions have been selected for the year-one program and three experiments are under way in the areas of Nonlinear Modeling, Computer Vision for Failure Detection, and Decentralized Control.

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Control Technology Validation

NASA BASE TECHNOLOGY RESEARCH

- AUTONOMOUS ADAPTIVE CONTROL
- ON-ORBIT SYSTEM IDENTIFICATION
- ROBUST CONTROL METHODOLOGY

DoD SPONSORED RESEARCH

- DECENTRALIZED CONTROLLER FOR LSS
- COMPUTER VISION - FAILURE DETECTION IN LSS
- NONLINEAR MODELLING

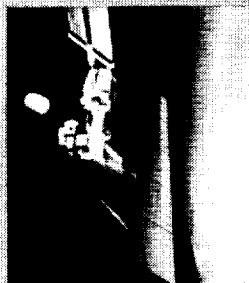
SPACE
STATION



LSS



EOS



LDR



ACCOMPLISHMENTS

- FULLY OPERATIONAL REAL TIME CONTROL GROUND EXPERIMENT FACILITY
- ADAPTIVE CONTROL PHASE I EXPERIMENT COMPLETED, PHASE II PARTLY COMPLETED
- SYSTEM ID PHASE I EXPERIMENT COMPLETED, PHASE II IN PROGRESS
- INITIATED AND IMPLEMENTED GI EXPERIMENT PROGRAM

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On-Orbit System Identification and Control

The corresponding figure depicts the recent experiment results of a new frequency-domain identification methodology for large space systems. The methodology is designed to support the main objectives of the estimation of system quantities useful for robust control analysis and on-line design modification, of on-orbit system identification under flight system constraints, and of automated identification processing.

The activity under this research plan is comprehensive because, in addition to conducting research in on-orbit identification methods, it also develops the technology to a level of readiness needed to support advanced spacecraft control system designs.

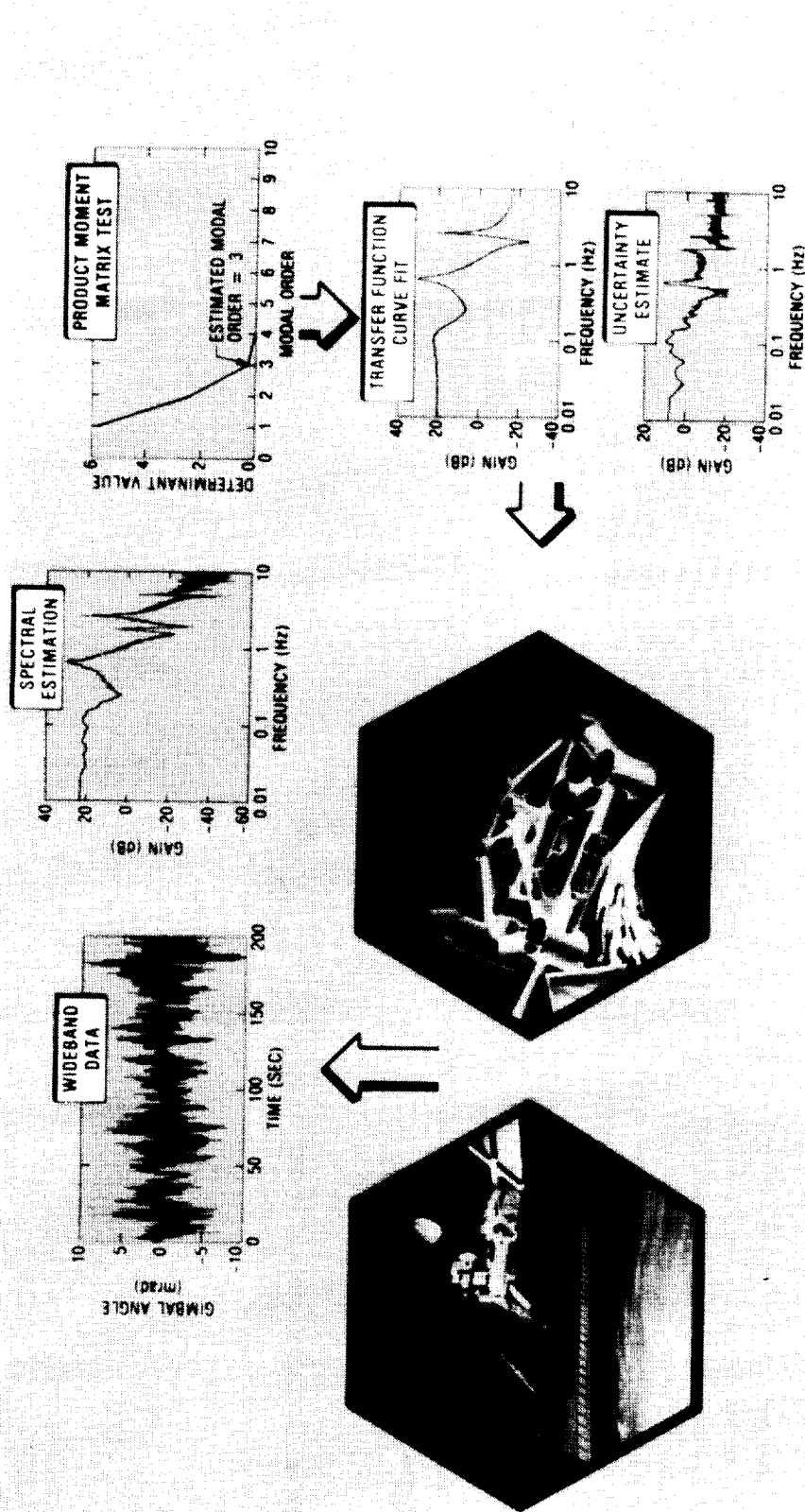
The specific interest in this work has been the use of system identification results to enable the on-line adaptation of robust high-performance control systems. The use of real-time on-orbit information for control modification has the potential to allow performance robustness and control accuracy beyond that which is attainable by using nominal system descriptions obtained solely from ground testing and analysis.

The application objectives have been particularly useful in focusing the identification methodology for realistic on-orbit testing conditions. Rather than trying to estimate the entire structure, as is typically done in ground structural testing, this methodology identifies directly the relevant transfer function parameters and uncertainty bounds that are necessary for on-line design and tuning of robust controllers.

The experiment results demonstrate that this identification process produces the reduced-order plant model which minimizes a uniform bound on the additive uncertainty. The identified parametric model's frequencies agree with a finite-element model to within 6 percent, and the modal dynamics are shown by the uncertainty parameter to be within 10 percent for moderate to lightly damped modes. Solutions to many practical and theoretical issues that were developed in the course of this work are discussed in a report, *Autonomous Frequency Domain Identification: Theory and Experiment*, JPL publication 89-8, April 15, 1989. This research represents a key milestone in a plan to develop a system of methods, algorithms, and software for the on-orbit identification of structural dynamic parameters and system-transfer function characterization for control of large space platforms and flexible spacecraft.

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On-Orbit System Identification and Control



PAYOFFS:

- ON-LINE TUNING OF SPACECRAFT AND PAYLOAD ROBUST CONTROLLERS
- HIGH ACCURACY DYNAMIC IMAGING SEQUENCES
- SIMULTANEOUS MULTI-PAYLOAD POINTING AND TRACKING

ACCOMPLISHMENT:

- KEY MODEL ORDER AND PARAMETER IDENTIFICATION METHODS DEMONSTRATED EXPERIMENTALLY
- A MAJOR MILESTONE TOWARDS AN INTEGRATED IDENTIFICATION AND CONTROL SYSTEM CAPABILITY

Adaptive Control Subsystem Development

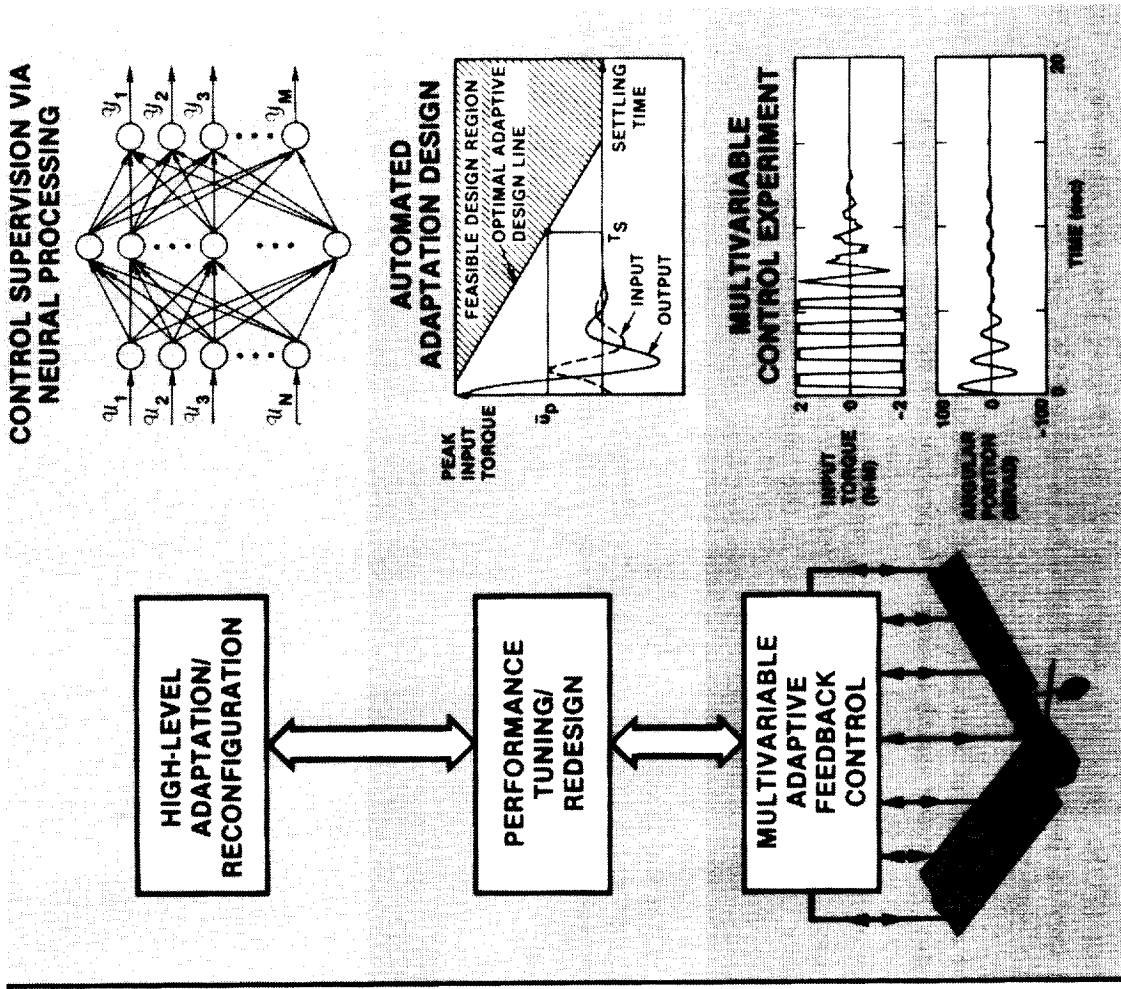
The objective of this research is to develop an adaptive control subsystem for application to emerging space systems, including future large flexible structures, space platforms, and advanced space-transportation vehicles. The overall approach involves a multilevel adaptation methodology, with the high-level controller for learning and supervision, the mid-level for controller tuning and redesign, and the low-level for robust servo-level adaptation. This approach will ensure high performance in the presence of major system changes, such as large parameter variations, hardware failures, anomalies, operational disturbances, and changes in mission objectives, as well as to local phenomena including drifting parameters, model uncertainties, and environmental disturbances. This concept will provide robust stabilization and control with enhanced performance for future space systems.

Recent accomplishments by the JPL and the University of Notre Dame team include the extension of nonlinear averaging techniques for scalar plants to the design of optimal adaptive multivariable systems, as well as the development of learning systems based on Petri-net/temporal logic and neural processing, for high-level control supervision of the overall adaptation design. These efforts have been focused to support the mid and upper levels, respectively, of the multilevel scheme depicted in the accompanying figure. In support of the low adaptation level, a six-input/six-output adaptive regulation experiment was successfully demonstrated for the first time in an Adaptive Control Experiment, verifying the technology in a full multivariable setting.

Research and development for fiscal year 1990 include the development of methodologies for the case of noncollocated sensors and actuators. When fully developed, this will extend the application of adaptive control to the most general class of spacecraft. Experimental work will include the testing of the robustness of the adaptive regulator under realistic actuator saturation, time delays, and adaptive pointing and tracking experiments. The averaging-based adaption designs will be incorporated into higher level supervisory functions.

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Adaptive Control Technology - Multilevel Control Adaptation



GOAL:
DEVELOP MULTILEVEL ADAPTIVE CONTROL SYSTEMS FOR ADVANCED SPACECRAFT

PAYOFFS:

- ENABLING TECHNOLOGY FOR
- ADVANCED GNC FOR SPACE TRANSPORTATION SYSTEM
- HIGH PERFORMANCE CONTROL IN UNCERTAIN AND TIME-VARYING ENVIRONMENTS

ACCOMPLISHMENT:

DEVELOPED

- MULTIVARIABLE THEORY FOR AUTOMATED ADAPTATION DESIGN
- 6 INPUT/6 OUTPUT EXPERIMENT
- LEARNING CONTROLLER BASED ON PETRINET/TEMPORAL LOGIC

Fiber Optic Rotation Sensor (FORS)

The objective of the Fiber Optic Rotation Sensor (FORS) task is to develop a 12-year lifetime, low-cost, lightweight, highly reliable, navigational-grade optical gyroscope with no moving parts. FORS is based on semiconductor optical sources, fiber optic waveguides, and integrated optical circuits operating at 1.3-micron wavelength.

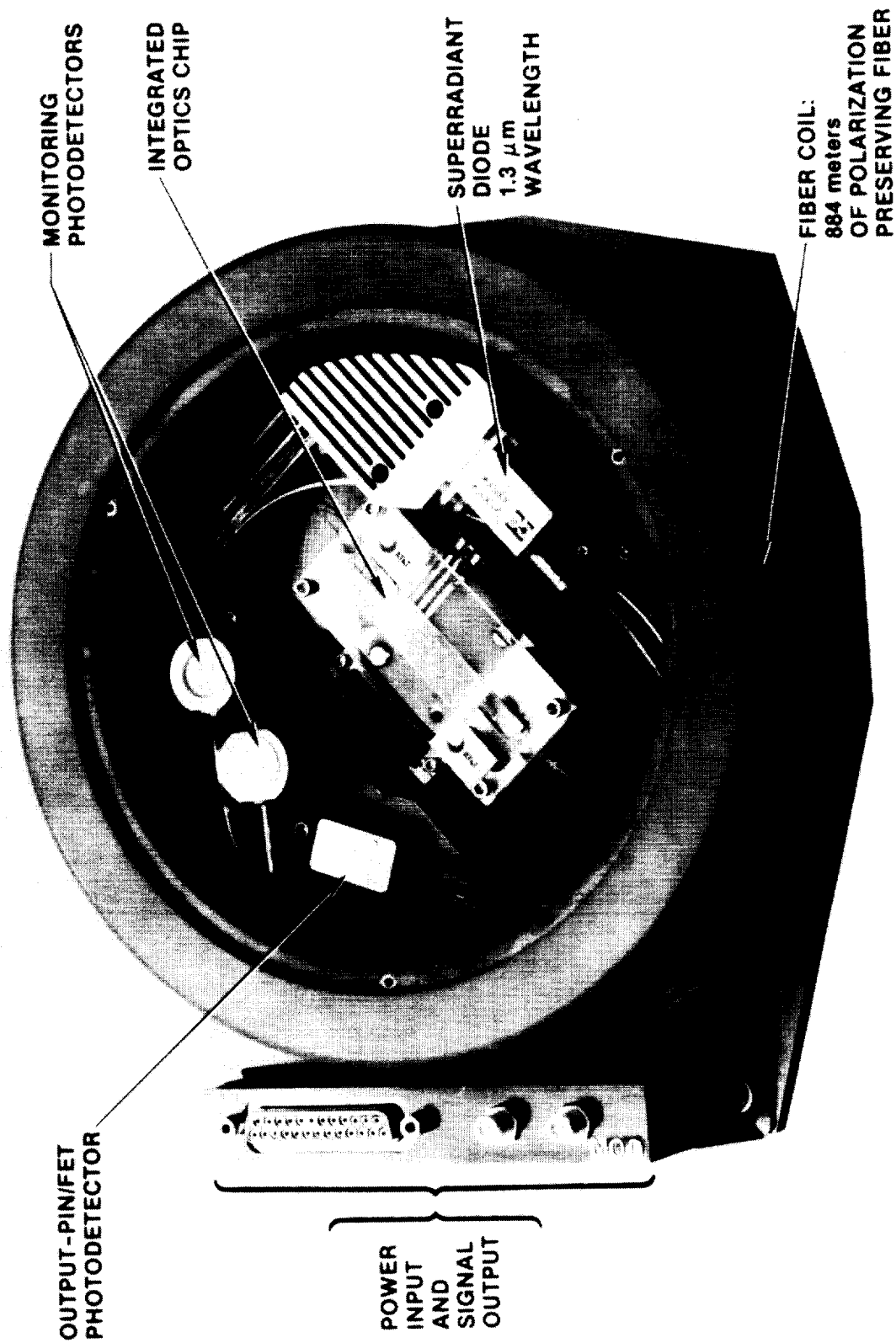
FORS achieves full single-axis-redundancy through the use of four independent single-axis gyros. Three of these gyros are mounted with their sensing axes orthogonal to one another, while the fourth is skewed to provide redundancy for any axis.

FORS incorporates an advanced integrated optics circuit and will perform all key signal-processing functions. FORS will feature a closed-loop, phase-nulling design that provides for operation over a wide range of rotation rates. Moreover, FORS will be rate-integrating, providing incremental angular-position readout in the form of optical beats. In this sense, FORS resembles a ring laser gyro (RLG), but does not suffer the RLG's tendency to lock-in at low rotation rates.

The advanced eight-component integrated optics circuit, fabricated for JPL by AT&T Bell Labs, consists of waveguides, polarizers, beamsplitters, and modulators integrated onto a single substrate. The circuit has been assembled in an advanced fiber-gyro breadboard and is presently undergoing functional and environmental tests at JPL. The gyro has been operated closed-loop and the optical beat readout concept demonstrated. Random walk performance of 7×10^4 deg/ $\sqrt{\text{Hr}}$, which is 1.4 times the theoretical limit of this configuration, was obtained in fiscal year 1989.

Technical Contacts: Bruce Youmans, JPL, (818) 354-8661
 Fernando Tolivar, JPL, (818) 354-6215

Fiber Optic Rotation Sensor Brassboard (With Three-Component Integrated Optics Chip)



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Spatial, High-Accuracy, Position Encoding Sensor (SHAPES)

The objective of this task is to develop a control sensor able to make simultaneous three-dimensional position measurements of up to 50 targets. These measurements need to be made with submillimeter accuracy and with a sufficient data bandwidth for system identification, shape, and vibration control of large space structures.

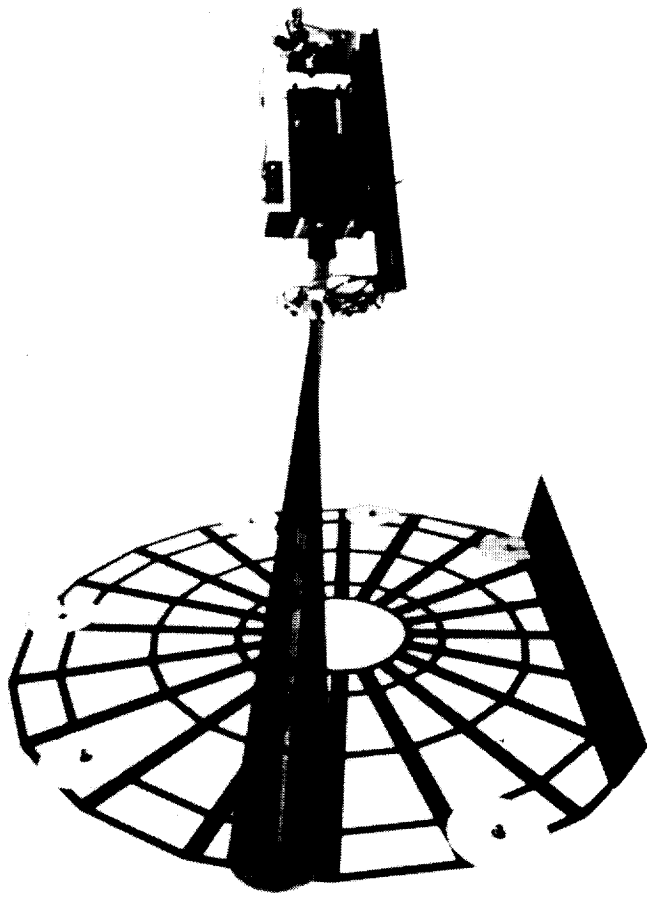
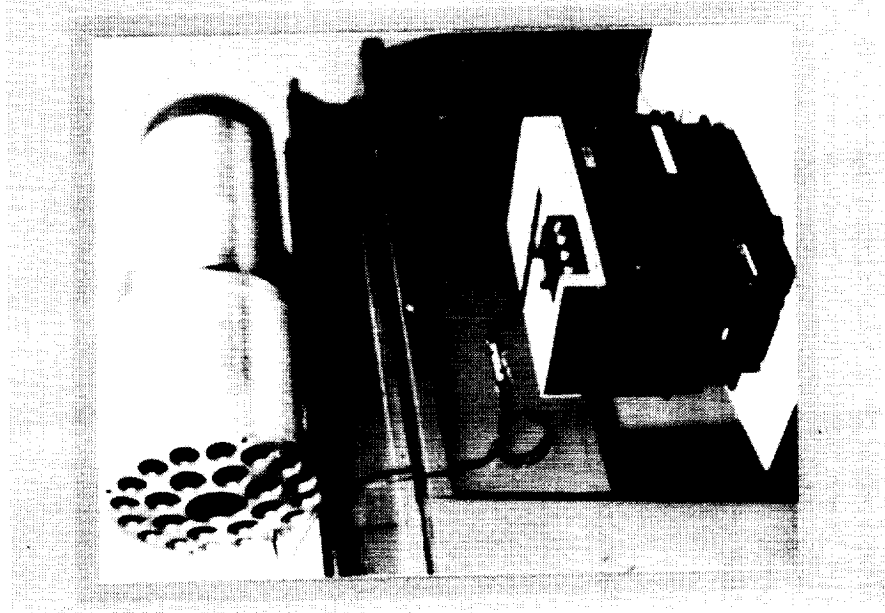
SHAPES, which combines optical angle measurements with time-of-flight range measurements, has the special capability of dynamically tracking many targets simultaneously. The sensor makes use of laser diodes, charge coupled device (CCD) imaging detectors, and a picosecond-resolution streak tube to provide three-dimensional position sensing of retroreflector targets. Multitarget tracking capability is required to determine both static and dynamic in-orbit characteristics of large antennas, platforms, and the Space Station *Freedom*. SHAPES measurements can be used to check structural alignment and overall geometry during each assembly phase of the Space Station *Freedom* to verify correct assembly. The SHAPES technology can also be used to determine absolute payload pointing/position from navigational base reference position measurements. A derivative of SHAPES also could be used as a rendezvous and docking sensor at ranges up to 40 km.

The principal accomplishment of fiscal year 1989 has been the development of a multiprocessor data acquisition and experiment control system for the three-dimensional breadboard. The three-dimensional breadboard incorporates a streak tube camera for the ranging function and a commercial CCD camera for angular measurements. The sensor will measure the positions of 24 targets with a resolution of 0.1 mm in range and 0.05 mrad in angular position over a 35° FOV at a data update rate of 10 Hz. Two-phase and dual-frequency operation of the streak tube will allow unambiguous range measurement to the maximum range of 50 m at the design accuracy. The optical components with a 35° FOV for the three-dimensional breadboard were developed. The figure shows the remote optical head that supplies the optical signal for the range measurement. A 14-mm F/1.4 lens was developed for the CCD camera for angular measurements.

Detailed characterization of the three-dimensional operation will be accomplished in fiscal year 1990.

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Spatial, High-Accuracy, Position Encoding Sensor (SHAPES)



Precision Metrology for Space Interferometers

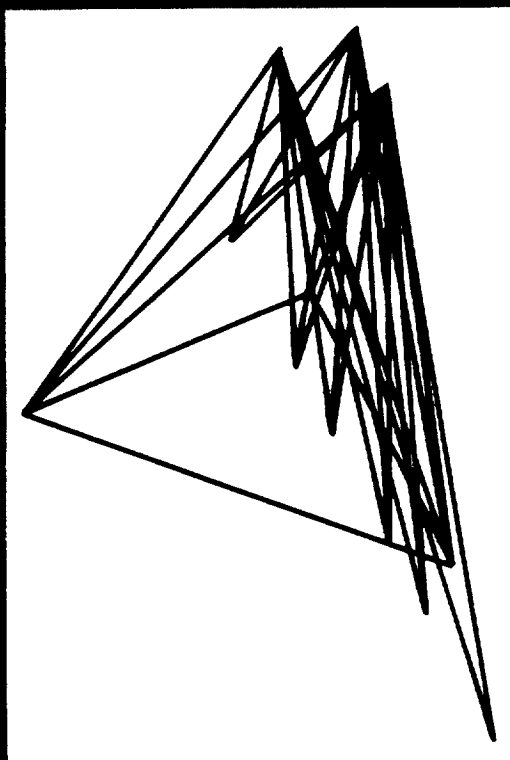
This task addresses the need for optical sensors that can provide inputs for control systems and can operate at levels of precision several orders of magnitude higher than present-day sensors. These levels of precision can be expressed as distances to nanometer accuracy and angles to microradians. The principal projected use for such sensors is in large spaceborne interferometers used for astronomy. An example of such an interferometer design is the one created as part of the Control Structures Interaction (CSI) task at JPL. The metrology system in this design uses 39 laser beams to determine the locations of the centers of 6 critical optical elements.

This task, which was new in fiscal year 1989, has concentrated on the determination of measurement requirements and the identification of the technologies that must be developed in order to make them. The number and type of measurements, such as angular and linear, which must be made in various situations are being examined, particularly for common requirements. Specific questions being addressed include the laser frequency stabilization, the design of beam-launching optics and retroreflective targets, athermalization of the metrology system, and the techniques for absolute, as opposed to relative, distance measurements. The output for fiscal year 1989 will be a development plan for these and related technologies.

Technical Contacts: Eldred F. Tubbs, JPL, (818) 354-4058
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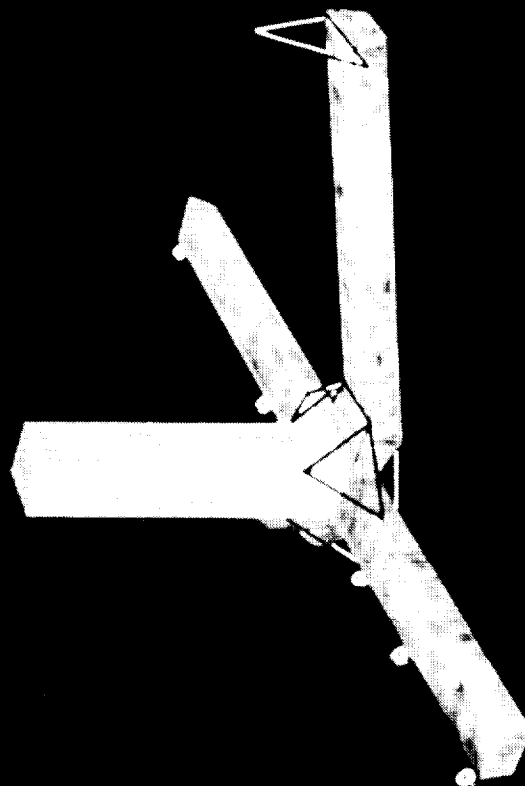
GOAL

IDENTIFY THE
NEEDS AND
DEVELOP THE
TECHNOLOGY FOR
MEASUREMENTS
AT THE NANOMETER
LEVEL OF PRECISION



PAYOFF

ENABLES SPACE
INTERFEROMETERS
FOR ASTROPHYSICS
AND ASTROMETRY



Data Systems

The Data Systems Program consists of research and technology devoted to controlling, processing, storing, manipulating, and analyzing space-derived data. The objectives of the program are to provide the technology advancements needed to enable affordable utilization of space-derived data, to increase substantially the capability for future missions of onboard processing and recording, and to provide high-speed and high-volume computational systems anticipated for missions such as the evolutionary Space Station and Earth Observing System.

The Data Systems Program supports fundamental research in such areas as laser diodes, work to select and provide the appropriate onboard processor technology for future NASA missions, and the development of two flight processors with special architectures. The ongoing support for solid-state laser research leads directly to the development of a nine laser diode array that is used in the Optical Disk Recorder. The laser research is also focusing some effort applicable to Space Station data handling applications. These devices are being developed to handle both the 300 Mbit/sec basic data rate and the much higher rates needed to support networking and computer internal communications. Complementary research is being supported to characterize the fundamental performance and properties of various alternative networking.

NASA missions require processors that will work very reliably in the space environment. Computer systems for missions in polar orbit and some planetary missions must operate reliably in high-radiation environments. The Data Systems Program capitalizes on the dramatic advances in electronics, computer systems, and software which are occurring in both the public and private sectors. It fosters and leads the development of technologies required to meet NASA's unique data systems needs. NASA technical expertise is being applied in cooperative arrangements with the DoD, and products from the DoD VHSIC program and other DoD developments are being assembled into processors for test and evaluation.

The Advanced Digital Synthetic Aperture Radar (SAR) Processor includes a special architecture and algorithms to process SAR data. The unit will have a compute rate of 6000 megaflops per second. The Massively Parallel Processor (MPP) is being used for ground processing of space image data, SAR data, and spectral analysis. The MPP utilizes 16,384 processors. The research applications developed on the MPP have verified the expected tremendous computational power of the MPP for the target applications. Researchers outside of NASA in several universities, research centers, and industry have been provided access to the MPP to gain an understanding of the capabilities of the MPP and have applied these unique resources to a broad range of computational problems.

Future objectives through the Civil Space Technology Initiative in High-Rate/High-Capacity Data include data system architectural studies for new space initiatives, significant advances in technologies and capabilities for onboard image processing, data compression, high-volume block access storage, data networks, spectrometry, and adaptive sensor control.

Program Manager: Paul H. Smith
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Computer-Aided System Design

The objective of this research was to enhance the computing systems design process by developing a technique for combining features of a systems architecture design tool and a software engineering tool to reduce simulation development time and expand simulation detail.

The Architecture Design and Assessment System (ADAS), developed at the Research Triangle Institute (RTI), is a set of computer-assisted engineering tools for the design and analysis of computer systems. The ADAS system, based on directed graph concepts, supports the synthesis and analysis of software algorithms mapped to candidate hardware implementations. Greater simulation detail is provided by the ADAS functional simulator. With the ADAS functional simulator, programs developed in Ada can be used to provide a detailed description of graph nodes. The Computer-Aided Software Engineering (CASE) tool, developed at the C. S. Draper Laboratory, automatically generates Ada code from data flow diagrams designed with a user-friendly graphical interface. The approach taken was to develop a methodology that combines the power of these tools to further automate the systems design process. To realize the full benefits of the combined use of these tools, the new technique had to use Ada code generated by CASE without modification, and the method could not affect results by slowing the simulation.

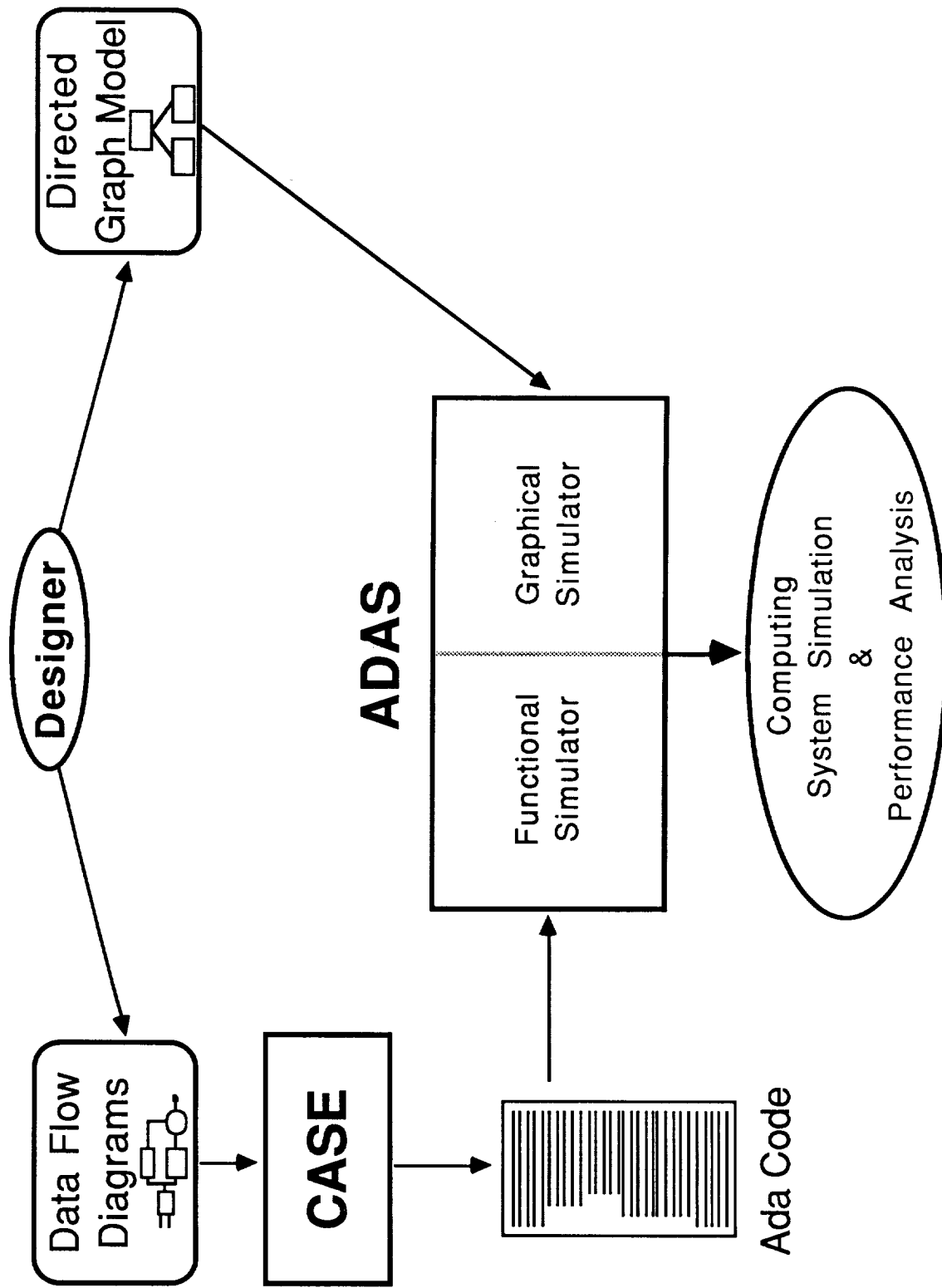
The feasibility of using the CASE and ADAS tools together has been demonstrated. Previously, to use the functional simulator the system designer wrote Ada modules to describe the action of each graph node. With the new method, these modules need only contain a call to a CASE-generated procedure. The user specifies the details of a graph node as a data flow diagram via the CASE interactive user-interface. CASE then generates the Ada code. When the procedure call is performed, the appropriate code is automatically located and executed. Two functional simulations were developed for matrix multiplication, one using handwritten code and one using calls to CASE-written procedures to define the necessary user-furnished code. The simulations were executed using the same data set, and the results were identical, demonstrating the viability of the enhanced method of developing functional simulations.

The new method for developing functional simulation designs has several benefits. The systems architect can specify software using block diagrams similar to familiar engineering notation. The level of programming expertise needed to use the functional simulator is greatly reduced, which can influence more designers to utilize this feature of ADAS, resulting in better systems design through more detailed modeling. RTI has provided details of this enhancement to other ADAS users. The design process for software functional simulation and for hardware graphical modeling has been made similar. Both methods use graphical representations created with interactive interfaces. The use of CASE in the development cycle promises to shorten the development time where functional simulations are employed.

The demonstration of this enhanced method for creating functional simulations will be continued using more complex examples. ADAS users will be educated on the use of CASE and the methodology for using CASE-generated code in functional simulations. ADAS applications will be used to test planned enhancements of the CASE tool as development progresses. Also, the use of library management tools will be investigated as a method of organizing functional code modules to give ADAS users additional flexibility.

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Enhanced Methodology for System Design



Spaceflight Optical Disk Recorder

High-rate, high-capacity data storage has been identified as an enabling capability for Earth observation and geostationary missions in the 1990's and beyond. To this end, a program has been established to develop a high-performance optical disk recorder with the following features: erasable, rewritable optical media; random-access data playback; capacity to 1 terabit (120 gigabyte); up to 1.8 gigabit per second input and output rate; and configurable, expandable architecture to satisfy various applications.

The key technologies that form the basis for the system are 14-in. magneto-optic media, 10-element diode-laser arrays, and a multitrack electro-optic head. The areal density of optical media is projected to be 8 to 20 times that of magnetic media. High rate is obtained by the use of a diode array and supporting electro-optic head to write, read, or erase eight simultaneous data tracks on each media surface. The per head data-rate goal is 150 megabits per second. The packaging concept is a dual-sided disk, two heads, and supporting electronics in a drive module. An associated modular controller is to be developed in a companion program to produce a configurable, expandable system. Multiple-drive modules can be utilized to obtain data rates in excess of 1 gigabit per second. This rate exceeds that of any other known or planned optical recording device or flight tape recorder.

A phased development is under way involving three separate contractors and a LaRC in-house effort. Other government organizations are participating, and related Small Business Innovative Research (SBIR) contracts exist. The basic technologies have been demonstrated. The current emphasis is on technology enhancement and development of a laboratory brassboard to address fundamental engineering issues associated with flight.

During the past year, a new laser structure has been developed that enables more efficient, thus longer-lived devices, glass substrate media have been produced and undergone environmental testing, characterization of the breadboard E-O head has begun, and the goals of the brassboard drive have been redefined to reflect Navy participation in the program. This will accelerate the development of a flight demonstration unit. The requirements for a breadboard controller have been established, and design has begun. Recorder development has been incorporated into the OAET Civil Space Technology Initiative (CSTI) program.

Technical Contact: T. A. Shull, LaRC, (804) 864-1874

Optical Disk Recorder

**TEN ELEMENT
AlGaAs DIODE
LASER ARRAY
DELIVERED**

**CONFIGURABLE, EXPANDABLE
SYSTEM ARCHITECTURE**

**OVERCOATED
PREFORMATTED
MAGNETO-OPTIC
ON AL DISK
DELIVERED**

**TECHNOLOGY DEMONSTRATION OF ELECTRO-OPTIC HEAD
WRITE/READ/ERASE AT 133 MBPS
8 DATA TRACKS, 1 PILOT TRACK**

Imaging Spectrometer Flight Processor

Imaging spectrometer instruments for Eos and beyond produce data at rates that cannot generally be handled by available telecommunications links, nor completely accommodated by foreseeable onboard-storage capabilities. The necessity thus arises for addressing onboard data-processing/reduction technology to provide data compression and real-time geophysical parameter extraction. Successful application of these technologies can reduce significantly the channel transport costs for these larger, complex data types and provide greatly enhanced operational flexibility for these instruments. This task is highly focused on technology capability demonstrations which can be of direct benefit to the Eos High Resolution Imaging Spectrometer (HIRIS) and the Moderate Resolution Imaging Spectrometer (MODIS) instruments.

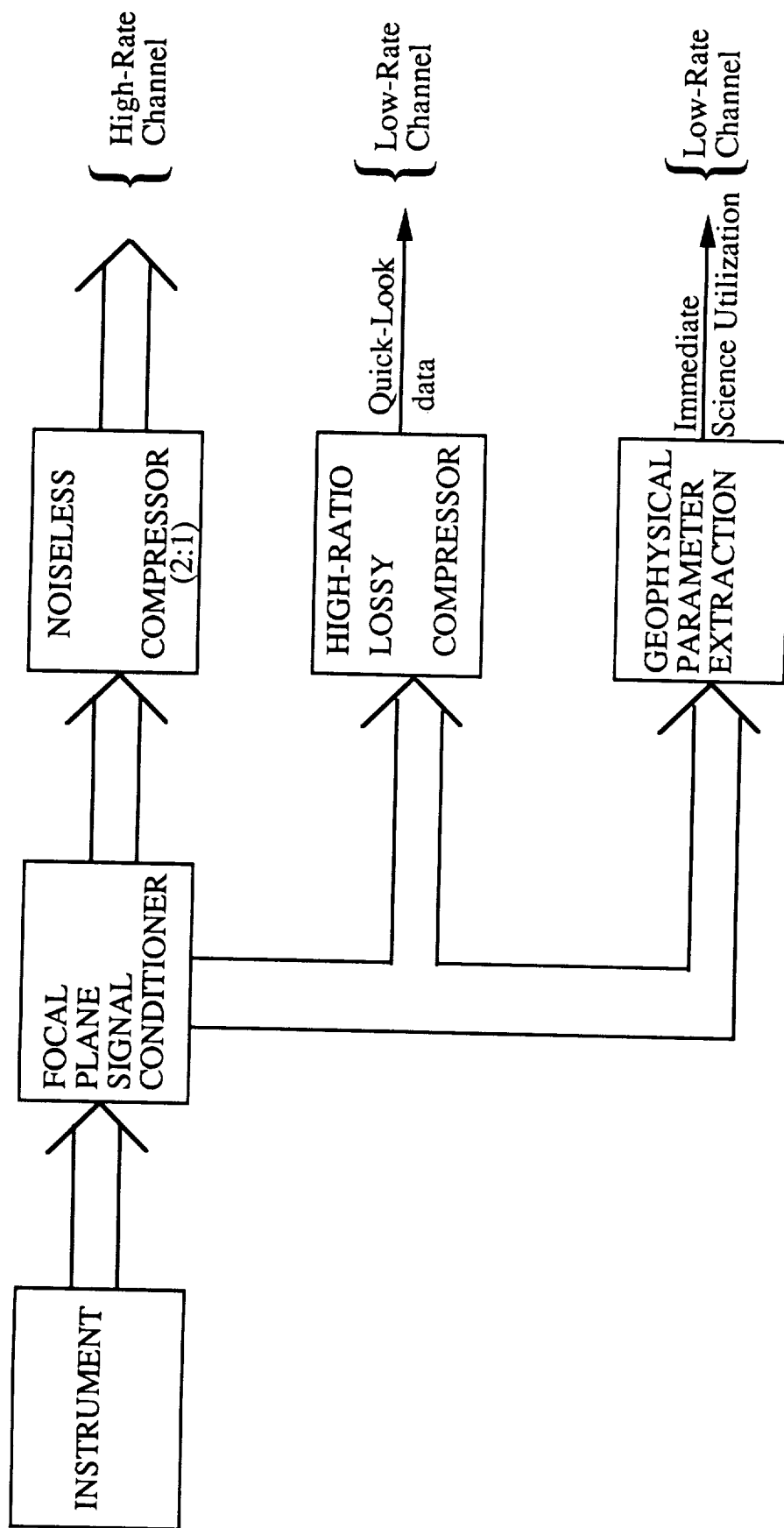
The objectives of this task are the development and demonstration of a laboratory breadboard signal-conditioning processor capable of providing gain/offset and solar-spectral irradiance correction-processing for HIRIS-type instruments; the development and technology insertion demonstration of a VLSI-based noiseless compressor-module capable of providing approximately 2:1 lossless compression of HIRIS data; the development and evaluation of high-compression ratio (greater than 50:1) lossy compression methods for imaging spectrometer type data; and the development and laboratory demonstration of algorithms and parallel architectures for real-time geophysical parameter extraction from imaging spectrometer data streams.

Major accomplishments during fiscal year 1989 have consisted of the fabrication and tested validation of one channel of a multichannel focal plane signal-conditioning processor compatible with HIRIS requirements; noiseless compressor algorithm validation with imaging spectrometer flight data and complete VLSI functional design of a noiseless compressor compatible with HIRIS requirements; computer simulation and testing of high-ratio lossy compression algorithms using imaging spectrometer flight data; and algorithm design and validation for onboard geophysical parameter extraction and preliminary design requirements for onboard real-time geophysical parameter extraction processors.

The multichannel focal plane signal-conditioning processor will be delivered to the Civil Space Technology Initiative (CSTI) testbed at the end of fiscal year 1990. A complete technology demonstration of the noiseless compressor module, meeting HIRIS performance requirements, is planned for the end of fiscal year 1990.

Technical Contact: Jerry E. Solomon, JPL, (818) 354-2722

Imaging Spectrometer Flight Processor (Technology Utilization Scenario)



Software Productivity Research

The objective of this work is to develop improved predictive metrics of the software process that meaningfully relate the function and performance of products to the cost and effort required to construct and validate them, and to discover upper bounds for the factors that collectively make up productivity.

The key hypotheses in this research are that the principal cost factor of the software process is information, that the products themselves embody this information, and that there are natural bounds on the human capacity to generate and transmit this information. The potential areas in which the process may be improved will be indicated by measuring the information generated, tracing its paths into products, other work products, or futility, and by calculating the effectiveness of organization, methods, and tools in reducing the amount of information needed or the labor required for its capture, integration, and validation.

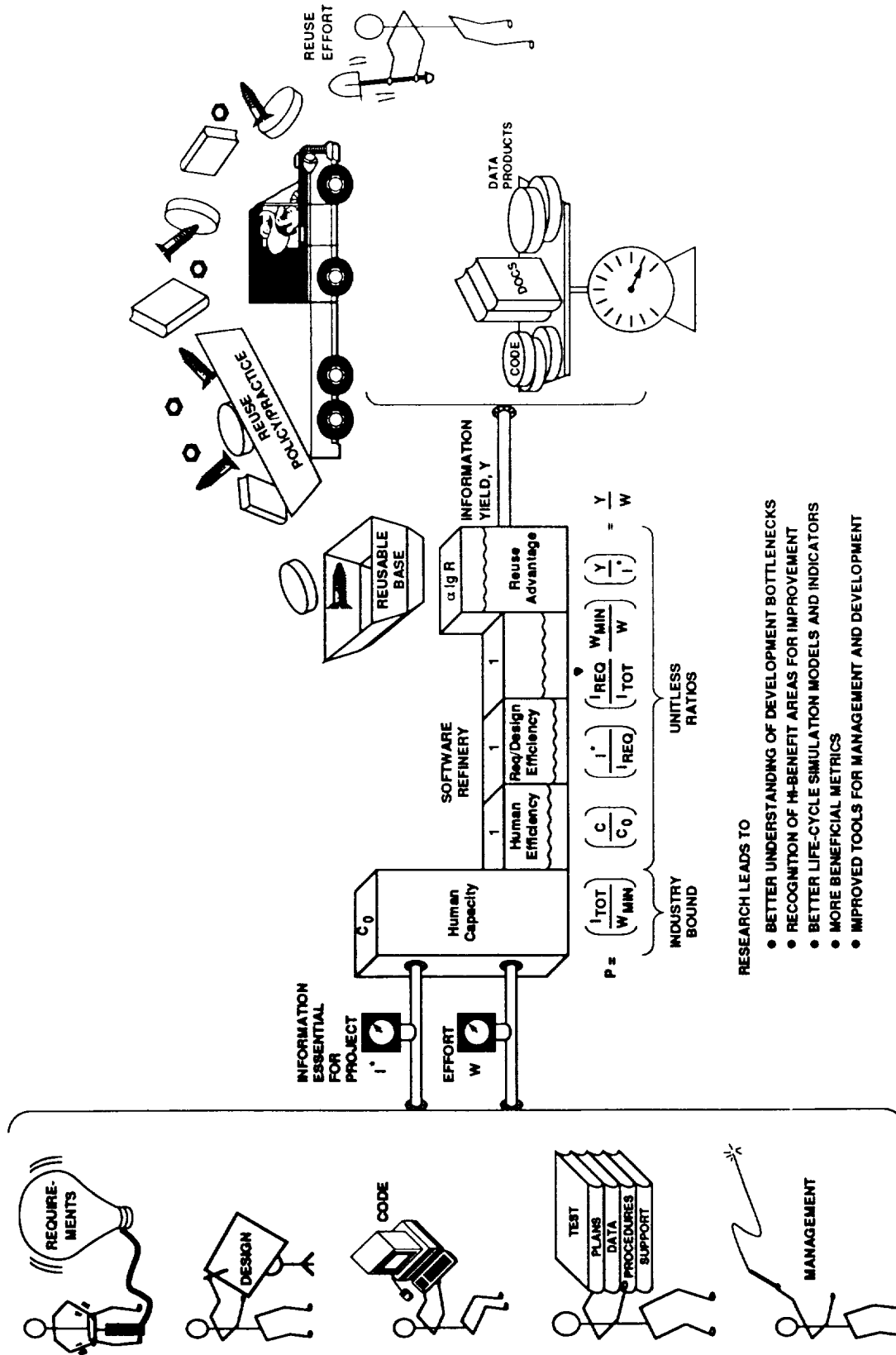
In the past, productivity has typically been measured in lines of source code, object code instructions, Halstead token length, McCabe complexity, function points, and various other complexity metrics, per unit effort. None of these has proved entirely satisfactory, and it has been shown that none is significantly better than any of the others in correlating the function and performance specified by requirements with the effort required to generate the products, assure their quality, and provide for their legacy in future reuse. It is thus necessary, if predictive measures are required, to seek other metrics that will suffice.

Current work in this RTOP has shown that, when defined as an information-in-information-out measurement, productivity separates naturally into five factors: a manifest constant (human information capacity) and four variable factors. The variable factors are mental efficiency, specification efficiency, tool efficiency, and reuse advantage. All the factors except the first are unitless quantities, being ratios of actual-to-ideal information and effort requirements. Improvements in the software process and development environment trace directly into one or more of these factors, and can be measured as decreased information or labor required from humans. It has been shown that productivity thus measured possesses an upper bound, much like channel capacity in communications theory. Moreover, it was shown that, ultimately, productivity increases can only come about through significant reuse in an automated production environment, but at a rate not greater than the logarithm of the size of the reuse base.

Future work will extend the theory to include the consequences of faulty implementation and validation of requirements and the effects of time-varying requirements, will measure and validate the productivity factors corresponding to the current level of practice, will accommodate the dual life-cycle process, and will publish the results for use in the dynamic life-cycle simulator tool.

Technical Contact: Robert Tausworthe, JPL, (818) 354-2773

Software Productivity Modeling



Flight Synthetic Aperture Radar (SAR) Processor

The objective of this task is to develop the technology to enable onboard processing of Synthetic Aperture Radar (SAR) data for an Eos type SAR mission. The processing is to include both the conversion of signal data to image data and the compression of the image data to achieve a further reduction in data rate. The specific goal is to demonstrate in flight qualifiable hardware that data processing can be performed within the weight and power constraints of 100 Kg and 500 W, respectively.

Current Earth-viewing SAR systems, even in their experimental states, produce large data rates and volumes that tax transmission link technology and ground data-processing technology. As these systems develop into operational status (such as for global change monitoring), the data quantities will become staggering. The onboard processing with data compression will result in rate reductions of between 50 and 100 to 1. This reduction can be applied to the routine mapping that is expected to constitute the bulk of the data, while the raw signal data could still be transmitted for special processes and experiments. A second significant benefit of the onboard processing is the capability to transmit the compressed images in real time to remote sites via a relatively simple direct broadcast and receiving system.

The SAR processor will perform on the order of one billion operations per second; that is, with supercomputer performance. The only significant signal processing development for spaceborne applications is the Defense Advanced Research Projects Agency (DARPA)'s Advanced Onboard Signal Processor (AOSP) program. However, the AOSP is intended for more general purposes and falls about an order of magnitude short in performance. There is no other development targeting anything close to the required level of performance this coming decade.

The preliminary requirements were completed based upon the current understanding of the Eos SAR system. A system design was developed to the point where conservative power and weight estimates could be made for various performance levels. A presentation was made to the Eos SAR Science Team, who endorsed the technology development direction and approach. This task is currently headed toward closeout early next fiscal year. There is no funding planned after fiscal year 1989 except for CSTI augmentation funds in fiscal year 1991, and the probability of obtaining these funds is marginal at best. Efforts are being made to seek support outside of NASA since this technology is considered to be a very important part of the Radar Program at JPL.

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Flight Synthetic Aperture Radar (SAR) Processor



• ON-BOARD SAR PROCESSOR PROVIDES REAL-TIME DIRECT BROADCAST OF IMAGE DATA TO LOCAL RECEIVING SYSTEMS

• APPLICATIONS INCLUDE OFF SHORE OIL, MARINE TRANSPORTATION, COMMERCIAL FISHING, GOVERNMENT OPERATIONS (NOAA, NAVY, COAST GUARD)

Spaceflight Optical Disk Recorder Controller Development

The objective of this companion program to the Spaceflight Optical Disk Recorder (SODR) development program is to develop a versatile, modular controller that, when combined with SODR disk drive modules, will provide high-performance mass storage systems that meet NASA high-rate, high-capacity spaceflight needs of the 1990's and beyond. The system goal is capacity greater than 1 terabit (120 gigabyte), up to 1.8 gigabit-per-second input and output rate, and configurable, expandable architecture to satisfy various applications.

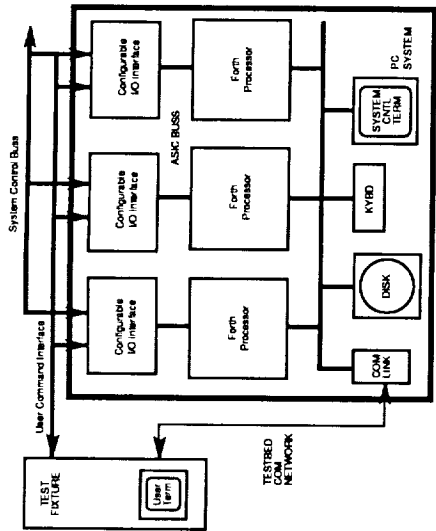
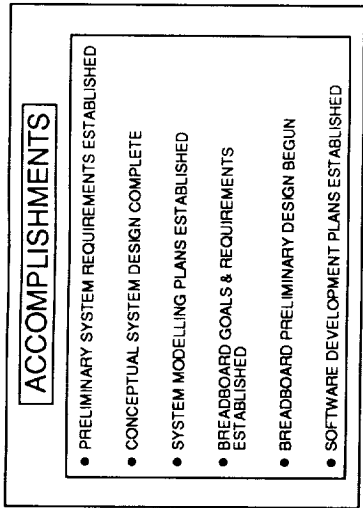
The thrust of this program is the development of a system architecture and controller which allows development of a generic drive unit and provides application-specific user interfaces and expansion in rate and capacity. The focus of the program is application aboard polar-orbiting platforms in support of Eos.

A phased development is planned from breadboard through engineering development and flight qualification. The current emphasis is breadboard design and demonstration of two port operation of 150 megabits-per-second simultaneous read and write or 300 megabits-per-second read or write. This includes verification of system concepts, establishment of operational guidelines, and definition of user interfaces and commands. Breadboard development will culminate in integration with a brassboard drive unit and testbed system demonstration.

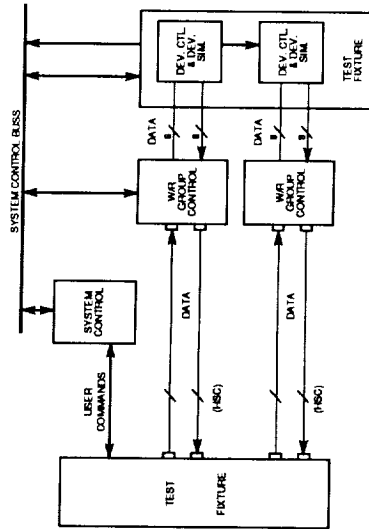
During the past year breadboard development has begun. Preliminary system requirements have been established and conceptual system design completed. Because it is not feasible to breadboard a complete system, plans for a system modeling activity have been established. The goals and requirements of the controller breadboard have been established and preliminary design begun. Software development plans have been established. A top-down hardware and software design approach is being used to enable easy transition to flight VLSI electronics during follow-on phases. Recorder development has been incorporated into the OAET Civil Space Technology Initiative (CSTI) program.

Technical Contact: T. A. Shull, LaRC, (804) 864-1874

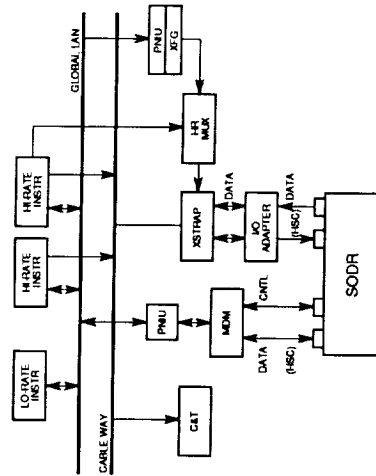
Spaceflight Optical Disk Recorder Controller Development



SYSTEM CONTROLLER CONCEPT
DEMO OF MULTI-PROCESSOR OPERATION



TOP LEVEL BREADBOARD TEST BED
TWO PORT OPERATION WITH DRIVE SIMULATOR



SODR TO EOS INTERFACE
ESTABLISHED

Erasable, Programmable, Read-Only Associative Memory for Electronic Neural Network Implementations

The objective of this project was to develop an erasable, programmable, read-only associative memory (EPROM) based on neural network models and to demonstrate its unique application potential as a "smart," highly parallel, fault-tolerant memory system for NASA's complex information processing tasks. The conventional techniques presently used are extremely cumbersome and are computational/memory intensive.

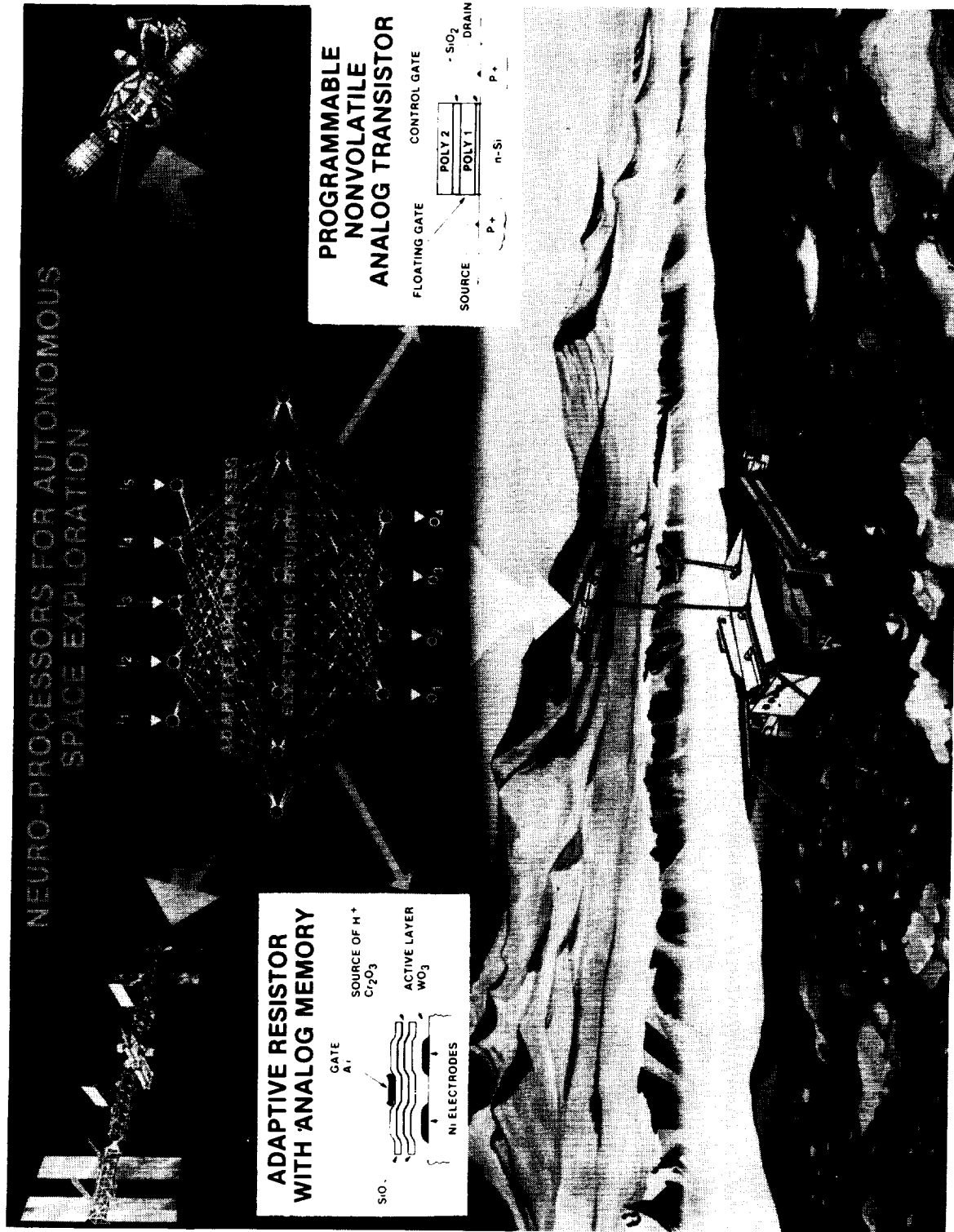
Artificial neural network architectures, derived from the models of massively parallel "circuits" in animal brains, promise an extremely robust, smart, fault-tolerant approach to information collection, storage, and processing. Extensive analysis and simulation studies in recent years have shown that the neural network approach is uniquely suited to solve certain computation intensive and ill-posed problems, such as pattern recognition, associative reconstruction, self-organization, and learning from experience, where conventional, digital-computing techniques are totally ineffective. To realize the true high-speed potential inherent in the parallel processing in neural networks, these architectures must be implemented in fully parallel hardware. Electronic implementations with nonvolatile, programmable-once, read-only synaptic elements have already been demonstrated at JPL. Their usefulness would be greatly enhanced with replacement of the binary synaptic elements by reversible, nonvolatile analog switches. Such "smart" memory systems would have a major impact on NASA's future mission applications in the areas of autonomous robotic control, operations sequencing and scheduling, and global optimization.

This review period was highlighted by the development of a nonvolatile analog memory device based on a floating-gate field effect transistor (FET). In addition to the tungsten oxide-based electrochromic thin film transistor (TFT) memory device, developed during the previous review period, this device is a strong candidate for further integration into an array structure. Furthermore, this structure is based on the MOS double-poly technology and is completely compatible with current VLSI-based neurons being developed at JPL. Three of the terminal test structures fabricated were in 9×9 and 18×18 μm geometry, using both n and p-type channels, and exhibited as high as 5 orders of magnitude of tailorable resistive range, long-term memory retentivity, and continuous gray scale. The technological constraints imposed by both types of synaptic switches were evaluated, and the system architecture was modified and optimized. The "smart" memory architecture is organized around a multilayered feed-forward implementation with three terminal analog, nonvolatile reversible synaptic elements.

In fiscal year 1990, the leading optimized device structure will be selected and integrated into a 32×32 array. These synaptic arrays will be interfaced with external VLSI-based variable gain neurons, finally leading to the development of "smart" memory systems.

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Neuro-Processors for Autonomous Space Exploration



MAX: Flight Multicomputer

The objective of this project was to develop a real-time, general-purpose computing system and environment that addresses the high reliability needs of interplanetary spacecraft and planetary rovers. MAX is a fault-tolerant parallel-computing architecture specifically adapted to tight resource limitations. It has been designed to support a large, heterogeneous collection of tasks in an unpredictable, event-driven environment, and is easily reconfigurable to a wide range of mission requirements.

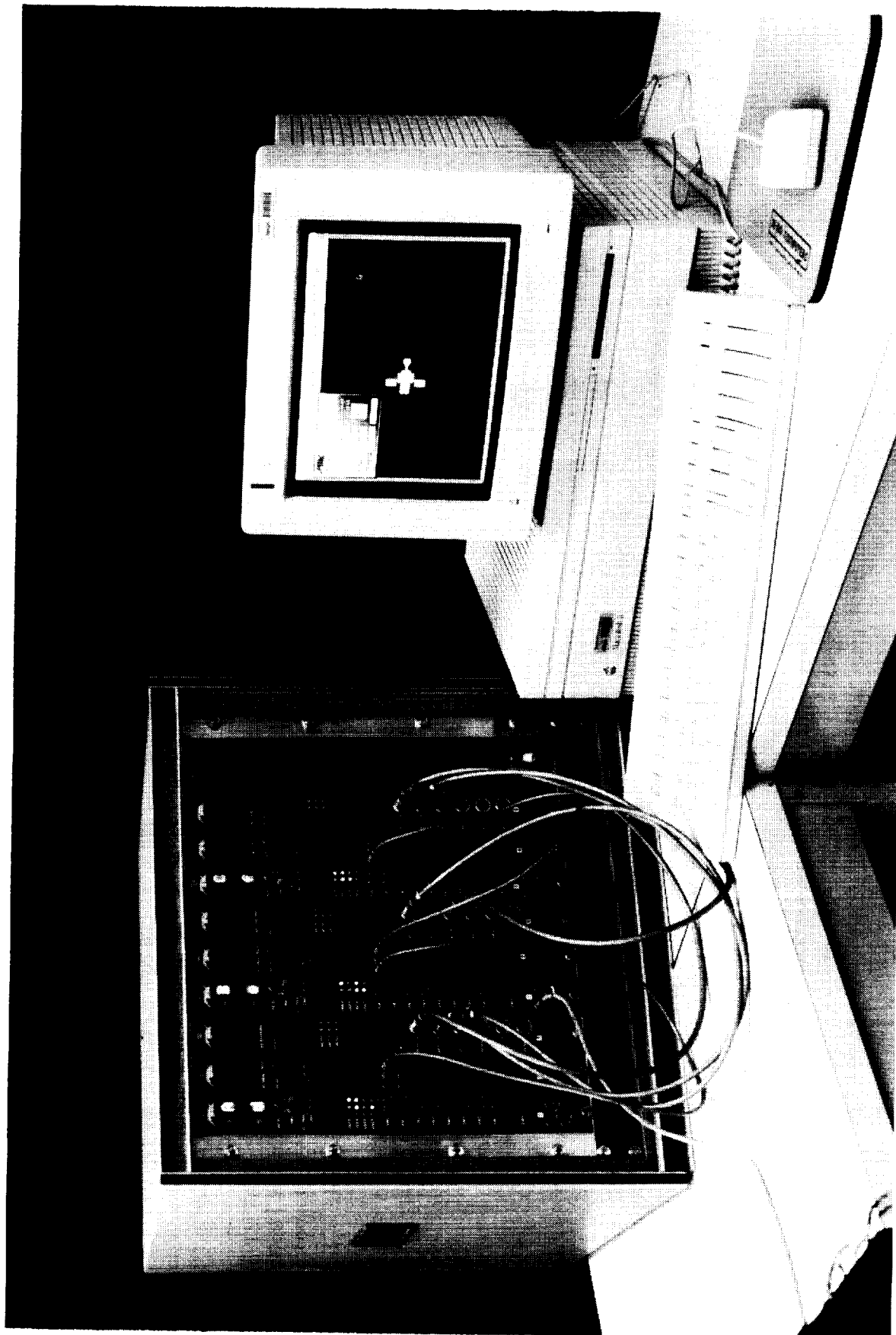
Onboard computational-processing technology has unique requirements and constraints. In order to keep costs down and make optimal use of the available hardware without sacrificing reliability, the MAX architecture was developed. MAX consists of any number of conventional computing-elements connected via a dual-network topology. One network operates as the prime data highway between these elements and I/O, and the other as a broadcast medium which synchronizes tightly coordinated real-time events and tasks. Orchestrating these elements is a very high level operating system that allows these tasks to execute in a highly nondeterministic, event and data-driven environment while maintaining appropriate redundancy for increased reliability.

With the advent of new high-performance spacecraft processors developed by DoD, integrated autonomous spacecraft operation is now possible. The MAX architecture leverages these new device capabilities into a unique system-oriented approach based on hardware resource pooling. This approach maximizes the utility of available hardware and software resources in order to minimize system mass, power, and volume without compromising reliability.

In 1989, the MAX architecture has progressed from concepts and design to an operational system. Four computing modules are functional, and the basic MAX operating system is nearly complete. Work is progressing on the implementation of fault-tolerant features and of software development tools. An application which controls a simulated rendezvous of two spacecraft in a dynamic environment has been demonstrated. Fiscal year 1990 plans include the fabrication of several more computing modules, completion of fault-tolerance features, and further implementation of software development tools. A demonstration of a local navigation algorithm for an autonomous planetary rover will be designed for execution in a MAX system. Long-term plans include the migration of the MAX architecture to Very High-Speed Integrated Circuit (VHSIC) components developed under DoD sponsorship. Such a system is projected to handle the foreseeable general-purpose computing-needs of NASA missions as well as of JPL.

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MAX: Flight Multicomputer



Spaceborne Very High-Speed Integrated Circuit (VHSIC) Multiprocessor System (SVMS)

The objective of the SVMS Project is to design an advanced, scalable multiprocessor computer system capable of executing very large, knowledge-based systems and other artificial intelligence applications requiring integrated numeric and symbolic processing. The SVMS is targeted for Space Station *Freedom* for intelligent control and monitor applications, e.g., power system, life-support system, large data base query system, maintenance-diagnostic system, and astronaut-advisor system. Other potential applications of the SVMS are embedded systems such as Flight Telerobotic Servicer and National Aero-Space Plane.

The SVMS Project is managed by a Project Team at ARC. The overall project is divided into three phases. Phase 0, a 15-month preliminary study, was completed in June 1988. Phase I, a 30-month effort, is the fabrication of three functional Brassboards to be delivered in December 1991. Phase II, a 48-month effort as an optional extension of Phase I, is the design and fabrication of a space-qualified SVMS to be used in Space Station *Freedom*. Project control and visibility will be effected by formal Preliminary Requirements Review (PRR), Interim Design Reviews (IDRs), Critical Design Review (CDR), and Final Design Review (FDR). This approach will minimize risk and ensure that the Project will be within cost and schedule and also will meet the technical quality specified in the SOW.

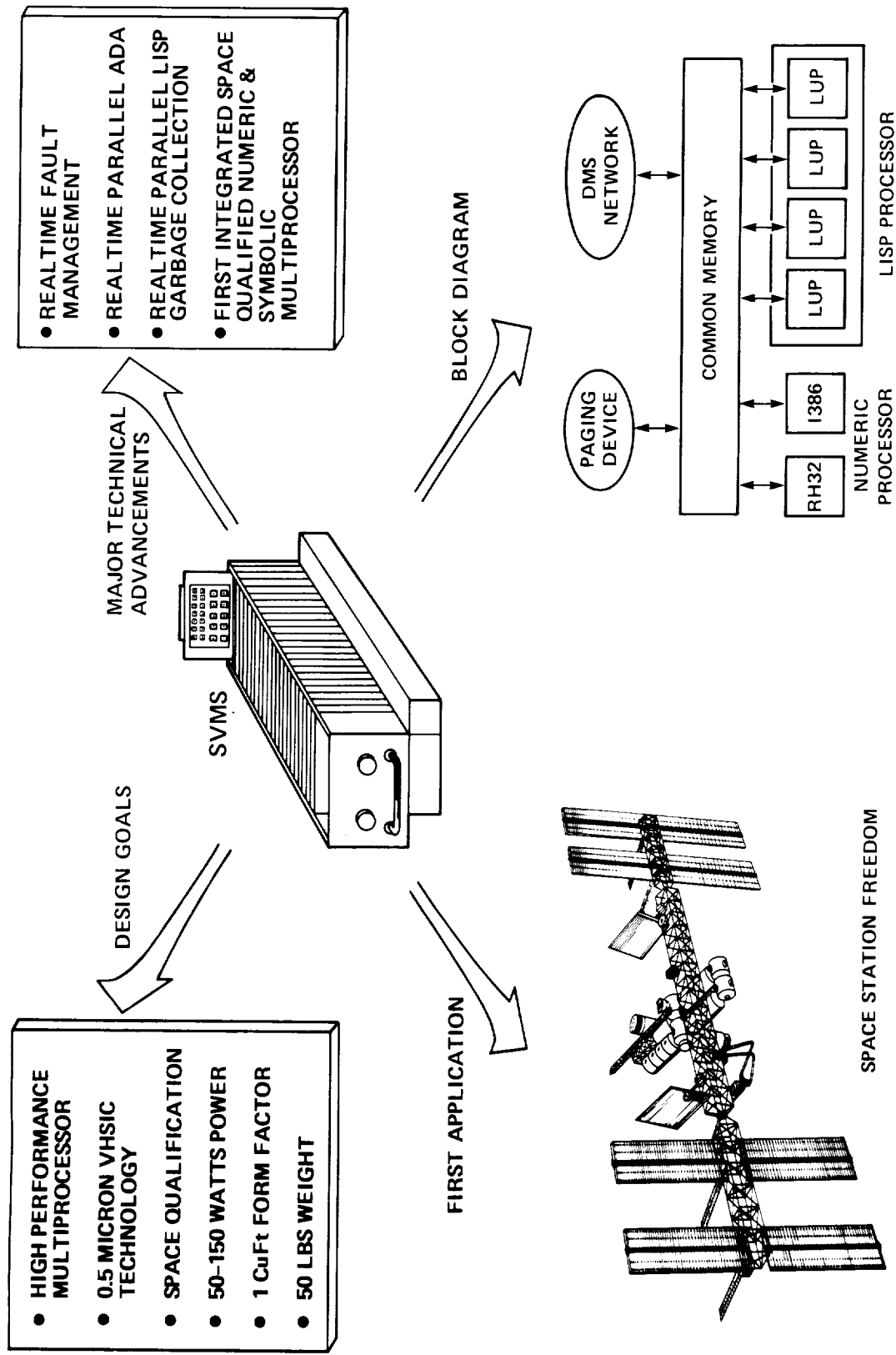
Major technical advancements are the first space-qualified integrated numeric and symbolic multiprocessor, real-time parallel Ada, parallel Common LISP, Common LISP Object System, real-time parallel garbage collection in LISP, real-time fault management for "graceful degradation" operation, computational power of 50 times faster than the Symbolics 3675 LISP machine (the industry standard LISP platform), and scalable architecture suitable for large and small applications. These advancements were purposely specified in the SOW approximately seven years ahead of what are currently available in Ada and LISP computations because onboard systems take a longer time to design and develop because of radiation hardening and space qualification.

The SVMS Project Team was organized in 1988 and now includes a staff of eight persons, with plans for two additional persons. Phase I contract work was started on June 8, 1989, and a signed contract is expected by the end of July 1989. All GFE scalar benchmark codes have been completed, and delivery to SVMS contractor will be in September as scheduled. A two-day PRR was scheduled for July 11-12, 1989.

Project control and visibility were handled through formal reviews as specified in the SOW. Effective communication and interaction with NASA/JSC for DMS interface and software development was integrated into SSE and effective communication and interaction with USAF/RADC for applications of the SVMS Brassboard was achieved. Scalar benchmark documentation was completed and timings were obtained per the agreed method with the SVMS contractor. Parallel benchmark development was started.

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Spaceborne VHSIC Multiprocessor System



Configurable High-Rate Processor System (CHRPS)

The goal of the Configurable High-Rate Processor System (CHRPS) is to provide the architecture, system control, and high-rate data-handling interfaces needed to support onboard compression, information extraction, and automated operations of high-rate imaging missions.

The next generation of imaging sensors will provide measurement capability at finer spectral and spatial resolution, resulting in data rates exceeding the capability of the Tracking and Data Relay Satellite System and exceeding the capacity of ground-processing systems and analysis teams. Interdisciplinary studies will require coordinated observations and integrated analysis of data from these sensors. The Civil Space Technology Initiative (CSTI) Data Systems Program is developing image processing and optical-disk recorder technology to support onboard data compression, information extraction, and data buffering for these high-rate missions.

The objective of CHRPS is to apply high-rate network technology and develop the packet telemetry-handling interfaces to enable the processing and buffering components to be configured for a range of operations from single-instrument data compression to multisensor fusion and feature extraction. The CHRPS development will produce a phased testbed to demonstrate technology components for the project applications such as Eos to support the integration of technology into space platform architectures and to support the evaluation of onboard processing functions. Support is building within NASA and the DoD to use the CHRPS testbed as a technology demonstration resource.

During fiscal year 1989, the two contract study teams preparing Phase-B designs for the Eos Data/Information System began special emphasis studies to produce project requirements for high-capacity processing onboard the Eos platforms. A draft requirements document for the CHRPS was developed and is under review, and based on this requirements document a preliminary design review was presented at the June Data Systems Technology Working Group meeting. A draft Project Plan for CHRPS was developed with the target of achieving approval by the GSFC Center Director by October 1, 1989. A significant effort by the CHRPS task managers and the Headquarters Program manager resulted in replanning the CHRPS into a 10-year project.

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Initial Testbed Configuration



Emulation of Information Networks

The research objective of this work is to define and develop an approach to the emulation of information networks which is suitable for determining performance characteristics of various data-communications protocols, for evaluating fault detection, identification and recovery (FDIR) techniques, and for determining the key network parameters of data transmission delay and blocking probabilities.

A seven-node mesh network design was implemented, with six microprocessors used per node for maximum emulation flexibility. Nodal functions are assigned to each microprocessor and stored in programmable read-only memory (PROM). The protocol and FDIR definitions are also embedded in PROMs for the evaluation of a particular network. A network user computer (NUC) that controls network service requests communicates with each node. The user services are implemented as statistical distributions of demand occurrence (that is, when the NUC requires network services) and duration (the length of time required to transact a demand occurrence). Each node and network user computer is instrumented (through programming) to record the demands, unique events such as data blocking, and event times for subsequent statistical evaluation. The user service demand (or work load) is variable over a wide range and allows the evaluation of the point where a network ceases to operate effectively. FDIR investigations are conducted by selectively disabling communication links or nodes.

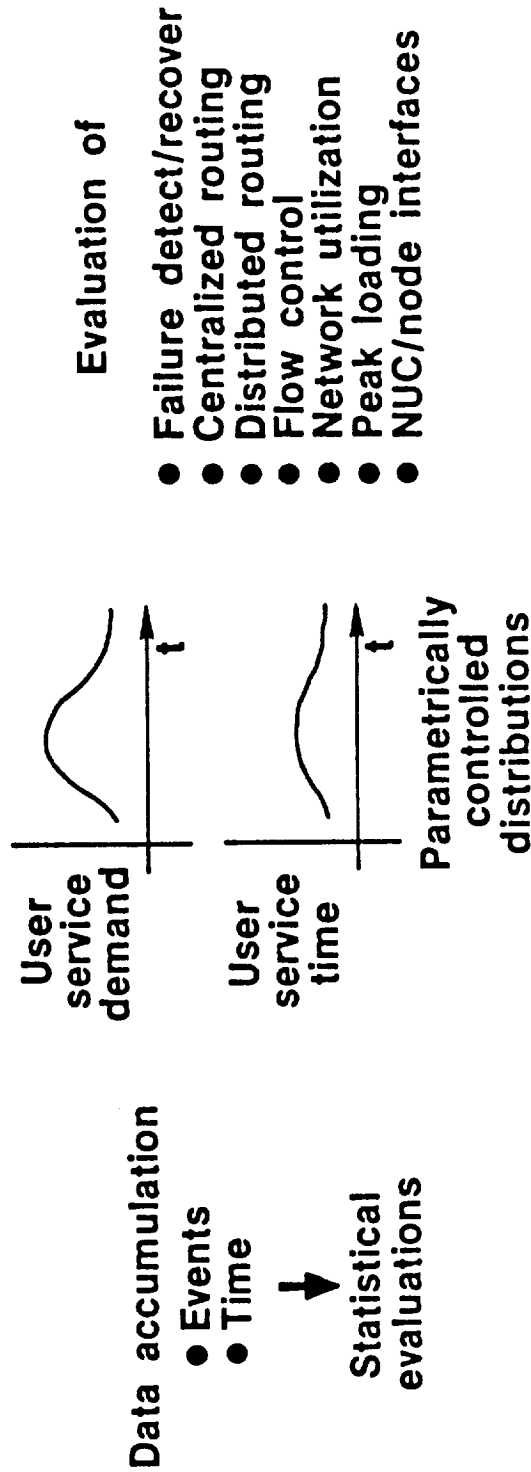
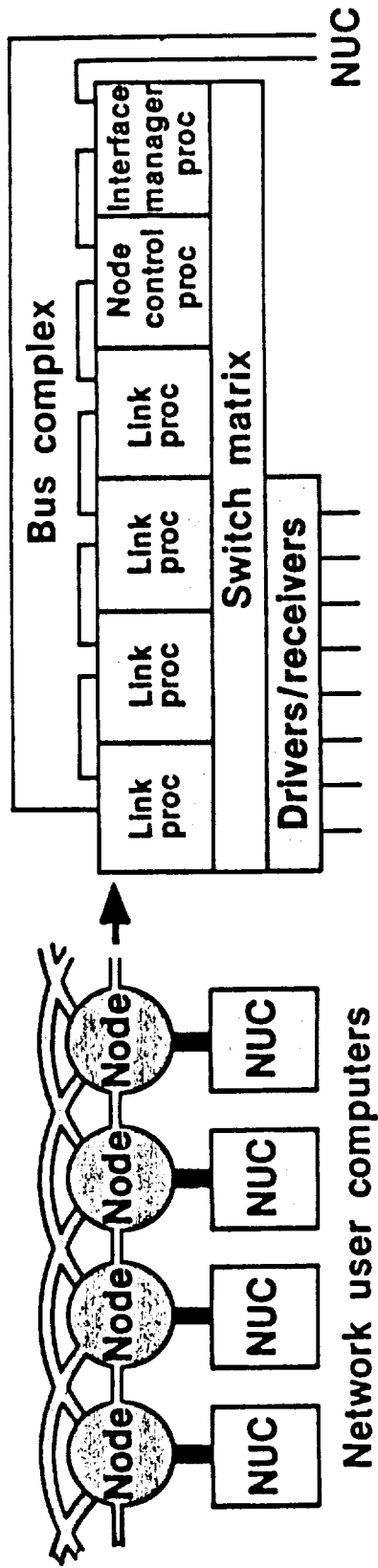
The network emulation concept and implementation are unique. A capability is available where critical network characteristics can be determined and evaluated. The data transmission delay statistics and the data blocking (no data transmission) probabilities can be assessed under work load, both of which are of paramount importance to time-critical flight control and to synchronous data reconstruction after transmission. Times accumulated, for fault detection and for reconfiguration around the fault, provide the basis for network fault tolerance and reliability predictions. The emulator capability has been used to examine protocol and FDIR methods for a developmental braided mesh network. Other methods, such as simulation on host computers, lack the degree of fidelity required to determine these performance and fault-tolerance variations.

Space Station *Freedom*, future aerospace transportation systems, and spacecraft can benefit significantly from network emulation results. These results can influence the selection of network architectures, protocols, and fault tolerance methods. As different topological forms of networks are possible for each unique application, this emulation approach provides the flexibility to examine a wide range of design options. This unique capability will permit examination of network trade-off and evaluation data, in detail, with fidelity better than simulation, and without the expense of building a network.

Currently, the full hardware software emulation is complete (seven nodes). Initial analyses have been conducted of a path search protocol/FDIR employed in the braided mesh network.

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Emulation of Information Networks



Use of Epsilon Decomposition Method to Solve Simultaneous Linear Equations

This work is an investigation of the usefulness of the Epsilon Decomposition (ED) method for solving large linear systems. ED is an important method because it is parallel by nature. It works by partitioning the system into strongly connected subsystems and then solving these subsystems. Simultaneous linear equations were used as an example of how this method works.

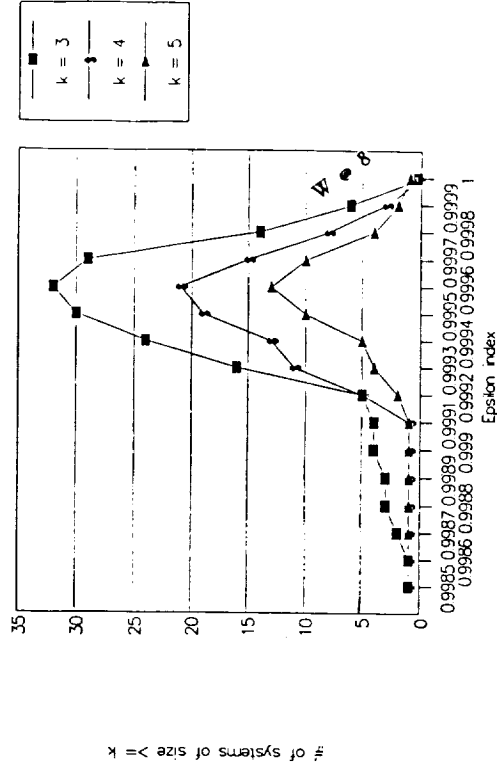
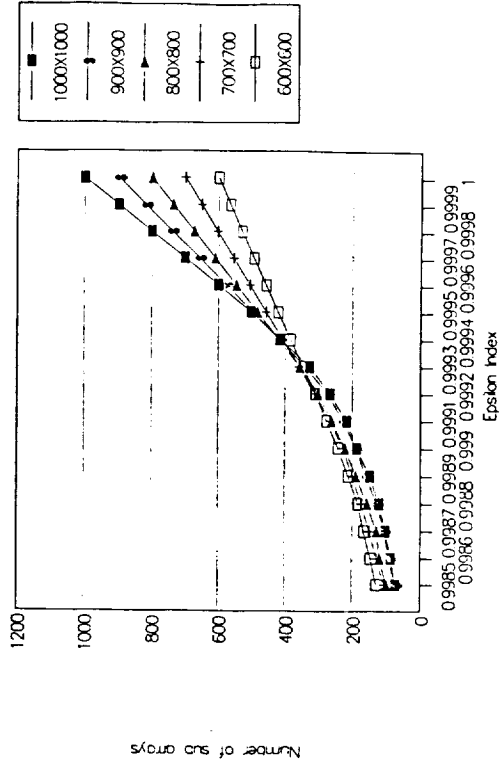
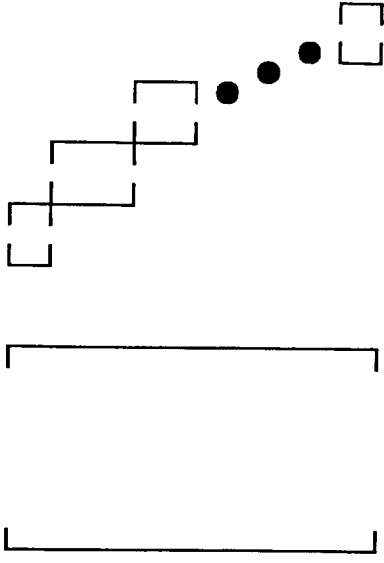
ED is a purely theoretical method. It offers no clues as to where the system should be partitioned. The first task was to find if a system with randomly generated elements can be partitioned at all. The second task was to find the value of Epsilon that partitioned the system. The third task was to estimate the gain obtained by using the ED method compared with more traditional ones.

It has been demonstrated that a system with randomly generated elements can be partitioned. Moreover, the partitioning point is predictable for a given size system. The partitioning point is data dependent, but always falls within a predictable range. The partitioning point is conveniently located somewhere in the top 0.5 percent of the sorted matrix; to find it sort the elements of the matrix in ascending order and then look at the top 0.5 percent elements. The location of the partitioning point is important because if this point cannot be found quickly the gain for using ED can be lost in the overhead of sorting the matrix. It is relatively inexpensive to find and sort the largest 0.5 percent elements of the system. Additional work is needed to find how much gain is obtained by using ED. The gain seems to be data dependent, with sparse matrices benefiting the most.

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Use of Epsilon Decomposition Method to Solve Simultaneous Linear Equations

- Any system can be partitioned using the correct Epsilon
 - An inexpensive technique for locating the range of partitioning points (Epsilons) has been found
- The range of partitioning points is predictable
 - Epsilon was found by sorting the top 0.5% of the matrix
 - The size and number of sub-systems is data dependent and can be changed by changing Epsilon
- Partitioning a system accelerates finding its solution
 - The gain ranges between 0.3% and 11%



Multiprocessor Modeling With the Architecture Design and Assessment System (ADAS)

The objective of this research was to develop a simulation model in the Architecture Design and Assessment System (ADAS) to verify the validity of the Algorithm to Architecture Mapping Model (ATAMM) and to provide a software environment for graph performance prediction.

A concurrent processing strategy, the Algorithm to Architecture Mapping Model (ATAMM), provides for the dynamic assignment of the nodes of a large-grain application algorithm graph to identical processors of a multiprocessor system in a manner which time-optimizes the execution of the graph. This research implements the ATAMM rules in ADAS and enables arbitrary application graphs to be readily entered, simulated, and evaluated. The top-level ADAS graph merges a scheduler node, which has several subgraphs and represents the heart of the operating system, with the nodes of the application graph to be simulated. The application graph nodes are based on subgraph node templates that provide the ATAMM-required functional subnodes, the control and data arc ports, and ports for the arcs interconnecting the application graph nodes with the scheduler node. Computer programs and procedures are developed for entering and analyzing an arbitrary graph, and an example graph is analyzed.

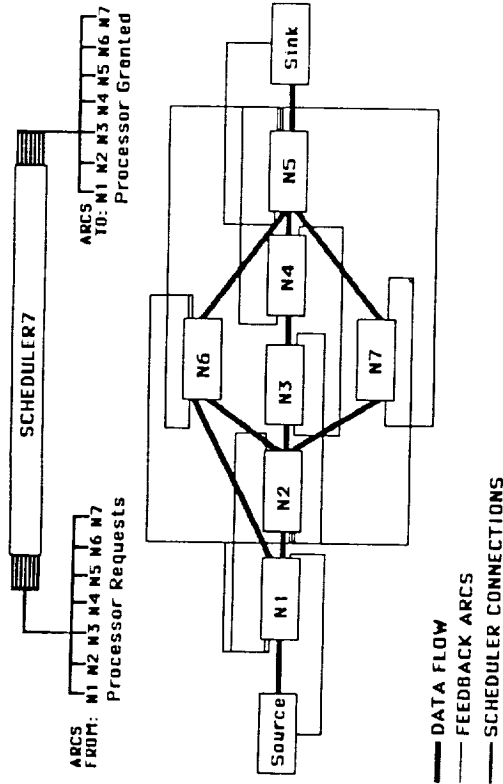
An ADAS model of ATAMM, which currently accommodates up to seven nodes in a graph, is complete. Two personal computer programs were developed for this work: one to simplify the entry of arbitrary graphs into the ADAS model, and the other to extract the data from the appropriate ADAS simulation files and plot the time-dependent processor requirements and throughput. A seven-node application graph example, which had been used by the ATAMM developers, has been entered into the ADAS model and simulated. Using the personal computer program, the simulation results have been extracted, plotted, and analyzed to determine the performance margin plot for the graph.

The performance results for the seven-node graph example duplicate those generated by the ATAMM developers and independently verify the validity of the ATAMM concept. The implementation of the ATAMM rules in ADAS provides a graph performance prediction capability in a readily available simulation tool not previously available in the government and industry.

The ADAS model of ATAMM will be enhanced to accommodate graphs having up to 63 nodes. The personal computer program will be improved to minimize or eliminate the editing currently associated with graph entry. The model will be used to analyze the performance of application algorithm graphs to be tested on multiprocessor hardware.

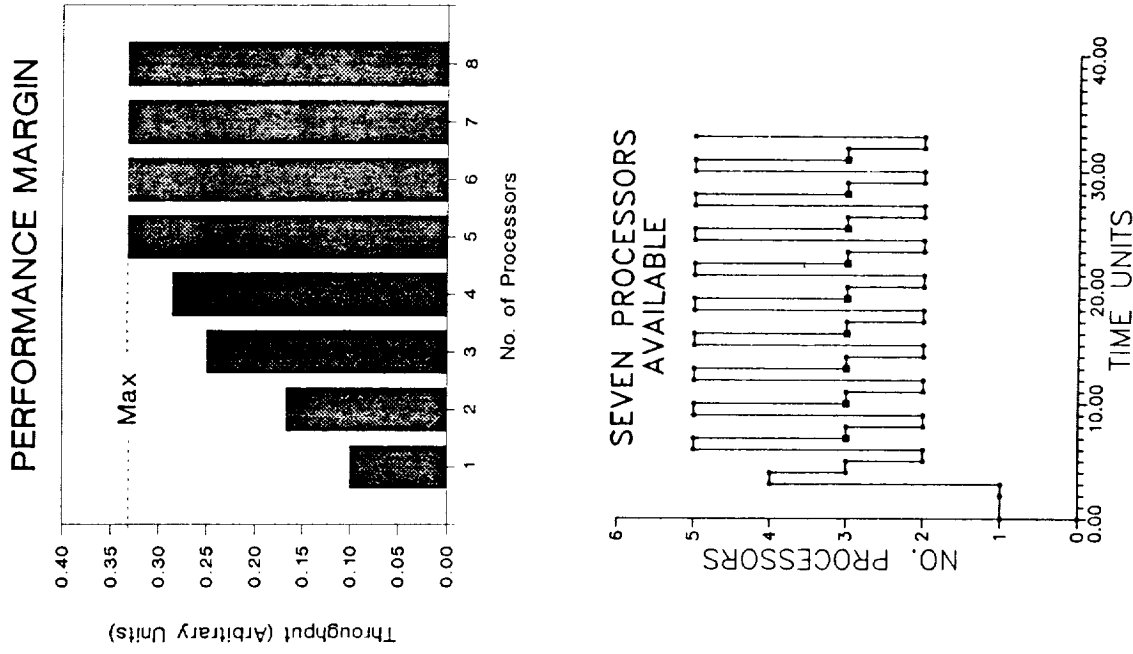
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ADAS GRAPH



FEATURES

- o ATAMM Rules Ensured
- o Arbitrary Application Graphs
- o Optimized Throughput
- o Graph-Limited Performance Prediction
- o Time Flow of Processor Usage
- o Readily Available Simulator



Human Factors - Aeronautics

The objectives of the Aeronautics Human Factors Research and Technology Program are to provide the technology base and capability to design effective crew-cockpit systems and to advance solutions to human factors problems affecting air transport and rotorcraft safety and effectiveness.

In the past 5 years, major steps in cockpit automation have occurred with the introduction of more flexible electronic displays and a variety of automated flight system management devices. They enable third-generation jet aircraft (i.e., B757/767, MD-80, and B747-400) to have fully automatic routine flight from takeoff to rollout, regardless of weather, and with reduced inflight work load. Higher levels of automation have been associated with certain problems as well as benefits. The air traffic management system has not kept pace to permit full use of these capabilities. Changes in ATC instructions on the flight crew's tasks, especially during descent or in terminal areas, result in very high work loads and, under some conditions, may divert the crew from monitoring and managing the aircraft's progress and safety.

Major steps in cockpit automation have occurred with the introduction of more flexible electronic displays and a variety of automated flight system management devices. A major focus of human factors research has been directed toward new human-centered interfaces and displays that provide increased margins of safety while taking into account the potential value of computer-based and automated system technology. The first year of research in the development of an Aviation Safety/Automation Program resulted in new displays for use by cockpit crews in high work load conditions in which human error could have very severe consequences.

For the period covered by this report, a major focus of human factors research has been directed toward pilot interfaces and displays that provide increased margins of safety while taking into account the potential value of computer-based and automated system technology. A major program was completed in the field testing of the Traffic Advisory and Collision Avoidance System (TCAS) which allows a pilot to be informed automatically of a potential collision with another aircraft and provides a flight path to avoid the other plane. Pilot decisions and consequences of them were obtained from these tests to verify the adequacy of the technology. Other simulations and tests were completed wherein a computer-aided system provided detection of dangerous wind shear conditions to the flight deck. These studies of human pilot behavior helped to establish the viability of such a detection device and provided significant information on how the pilot should respond to a wind shear alert by initiating different maneuvers.

In the area of helicopter research, NASA identified major sources of human error found in helicopter operations associated with emergency medical services. The National Safety Transportation Board had requested analysis of these unique operations because of the high accident rate associated with them.

A comparison of pilot performance with a side-stick controller was completed. The controllability of several different modes of coupling and of control priority was examined. Pilot preferences were obtained concerning the usability of various levels of coupling between side-stick controllers and auto-pilot systems.

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Pilot Preference and Performance Results Indicated Superiority of New Engine-Monitoring and Control System (E-MACS) Display Concept

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The primary objective of this research was to provide an advanced aircraft engine display system designed to exploit the capabilities of electronic display media for increased pilot understanding of system performance while simultaneously reducing pilot mental work load and error.

The underlying concept of this study was that a reduction in the mental work load associated with the utilization of displayed information may require that the information be provided in a form that is more directly oriented to the user's task. The area of interest for this study was secondary flight-display formats, with engine instruments as the specific application. This application area was chosen because it provides both a control task, engine power with throttle, and a systems-monitoring task. A part-task evaluation in the TSRV simulator was used to compare the E-MACS display with a modern, current-generation engine display format.

The E-MACS display provides an innovative interface to the engine system for reduced pilot work load and increased situational understanding. The E-MACS display format provides unique display elements tailored to the pilot's task. For the control task, a display element based on a model of engine performance characteristics was used. This display element provided a direct indication of engine thrust relative to a computed maximum thrust available value. For the monitoring task, the emphasis was placed on presenting quantitative information in a form that may be cognitively processed in a qualitative manner. Column-deviation indicators were used as the display elements for monitoring, where the deviation was between the actual and a computed ideal value.

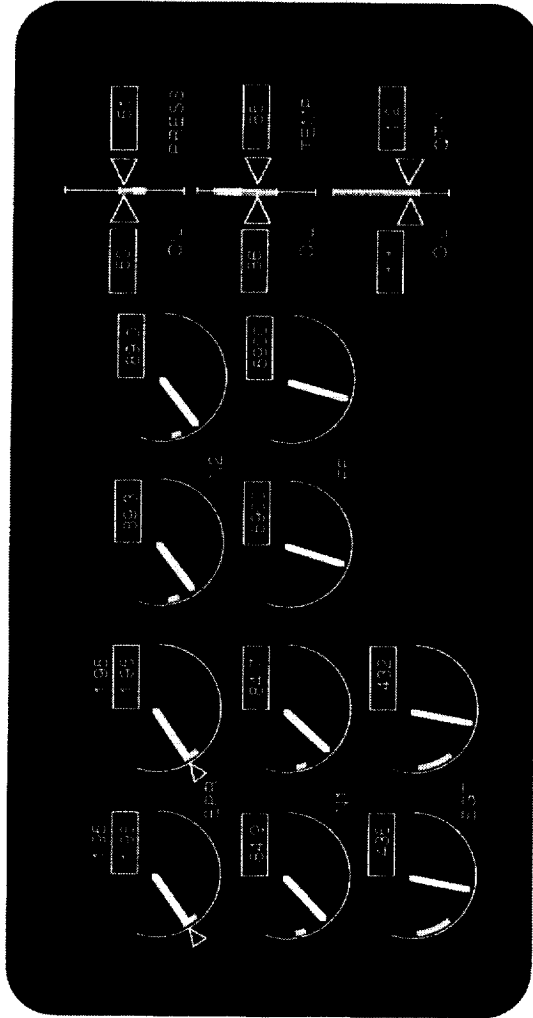
Sixteen pilots participated in a simulator evaluation of E-MACS. The test included takeoff and inflight conditions with both normal and fault (degraded and out-of-tolerance) conditions. As part of the evaluation, each pilot was presented with four different scenarios for each of the two display formats. Half of the scenarios involved fault situations. The subjective results of this test showed an overall preference for the E-MACS display relative to the traditional display. The monitoring display elements seem to allow holistic viewing of the system information. The most significant result is that the use of the E-MACS display resulted in a 100-percent detection rate for all system faults relative to a 56-percent rate for the traditional display (at the 95-percent confidence level).

The next major step in the evaluation of the E-MACS display will be the implementation of this concept on the TSRV aircraft. The figure illustrates how E-MACS will be implemented. A patent application for the E-MACS display (NASA Case No. LAR 14049-1) was filed with the U.S. Patent Office in November 1988.

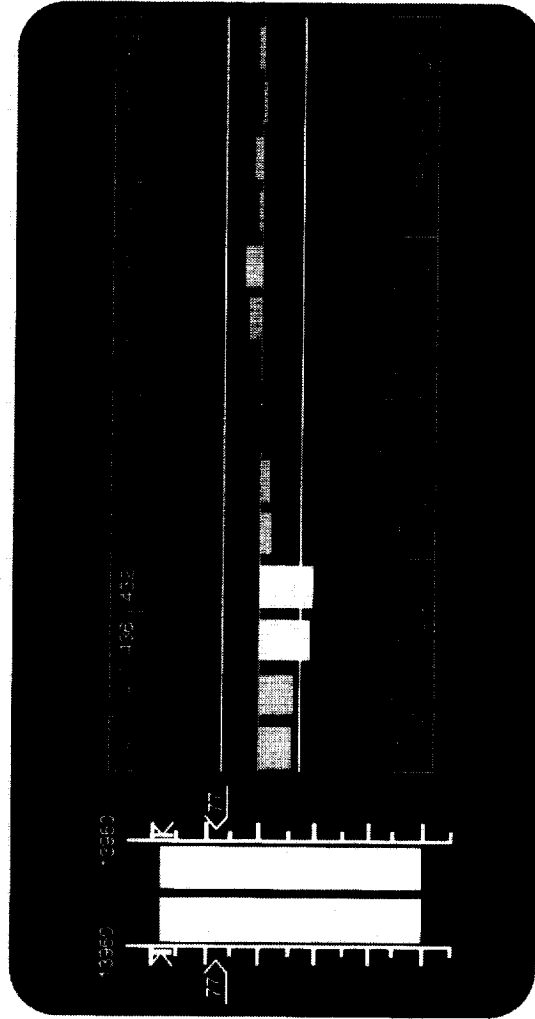
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Incorrect Sensor (EPR) - Similar to the 1982 Air Florida Accident

Traditional



E-MACS



Evolution of Transport Aircraft Automation

Although much has been accomplished regarding the automation of the first deck, there is still much to do. The workshop provided a valuable opportunity to exchange experiences regarding operations and training for automated aircraft. Continuation of such opportunities needs to be provided by the relevant organizations and government agencies.

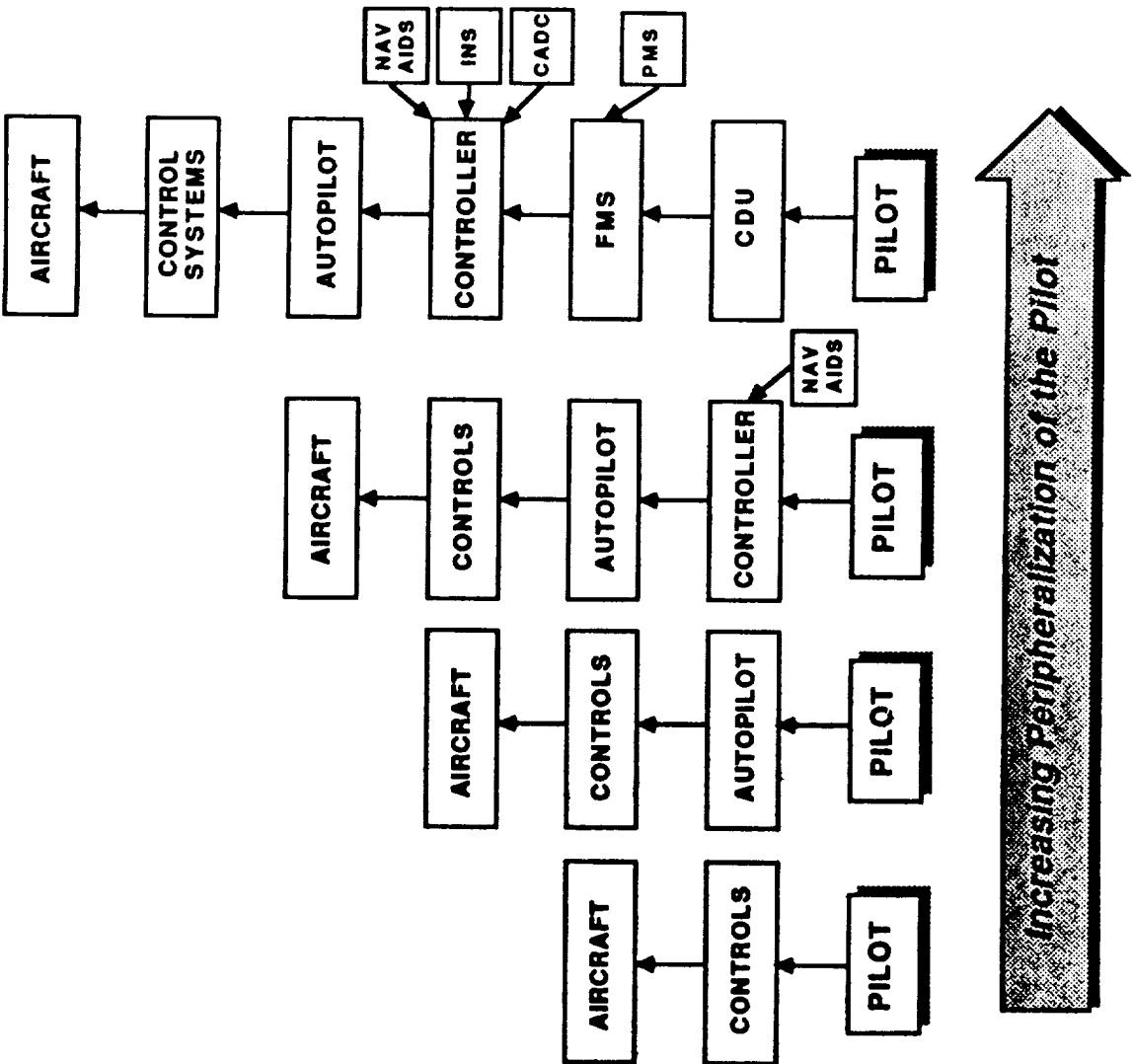
The need for quantifiable data concerning the implementation and interface designs for automated systems is also very apparent. Full mission simulations that compare alternate displays and test the performance of the entire system, including the ATC, the flight crew, and the aircraft, would be very helpful.

Improvement in the human factors aspects of the certification process is needed. Additional research, involving interface design, training, and operational procedures, is needed to better understand how to support the human role in an automated environment.

Improving our understanding of the air-ground interface is crucial for the future. This development is necessary if coordination of the planning and implementation of advanced automation for both the flight deck and the air traffic controller are to proceed in an integrated manner. Automation provides the potential for one part of an automated system to impact another, sometimes without direct human intervention. As a result, it is important to examine the implementation of automation as an overall system so that the design implications can be made visible before the operational phase commences.

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Evolution of Transport Aircraft Automation



Evaluation of Voice-Activated Controls

Low-level rotorcraft operations continue to impose high visual and manual demands on the pilots. Voice recognition systems have been proposed as an alternative method for pilots to enter commands and effect subsystem selections. Vocal commands should compete less for pilots' limited manual control resources than would manually entered commands during flight segments that impose high manual control demands. To determine the potential performance and work load benefits that might be derived by the use of vocal controls, a series of simulations were conducted at ARC jointly with the USAF. The research was conducted using a fixed-base simulation of an advanced-technology military helicopter. Pilots conducted military missions that included cruise, hover, and air-to-ground engagement segments. Control over various discrete tasks, including weapon selection, data-burst transmission, and counter-measure activation, was effected by voice command or manual bottom press. In the second simulation, a pilot-selectable altitude hold feature was provided on half of the flights, and simulated wind-gust disturbances were introduced at different times during the performance of the discrete tasks to determine the temporal pattern of disruptions with the two methods of entering commands.

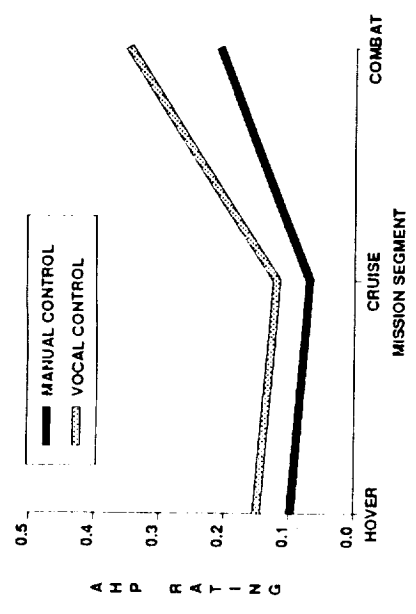
In Experiment 1, speech controls improved performance by reducing competition for manual response resources; discrete-task performance was degraded less during high work-load segments and vehicle stability was improved. This performance benefit was achieved at the expense of higher work load because voicing consistent commands to achieve adequate recognition accuracy and monitoring system feedback to ensure that the intended command was entered required additional time and effort. Experiment 2 replicated the earlier study and also evaluated the effect of automation (a pilot-selectable altitude-hold option) on performance with vocal or manual controls. When altitude hold was not available, the results of the first experiment were repeated. Vocal commands took longer to enter than manual, but they interfered less with flight-control performance than did manual commands during high work load segments, and work load was higher with speech controls than with manual. With the addition of altitude hold, however, the differences between vocal and manual input systems disappeared. Altitude hold reduced overall work load to the point that pilots had sufficient reserve capacity to control the vehicle and to enter, with either input device, discrete commands without becoming overloaded. Although altitude hold did not affect data-burst performance, weapons-selection response times improved. But vehicle-control performance was worse when unexpected events occurred, suggesting a reduced level of involvement or decreased readiness to respond.

The data from these simulations support the predictions of the multiple resources theory and suggest the potential utility of speech controls in reducing competition for manual-response resources, even though current voice-recognition system technology is not yet adequate to encourage their operational use for high-priority tasks. This research forms the basis for a principled assignment of vocal or manual controls to the performance of discrete functions in advanced rotorcraft to ensure that the maximum improvement in work load and performance will be achieved by the introduction of voice recognition systems.

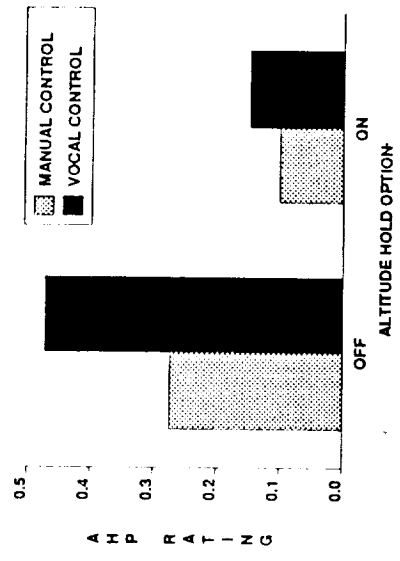
Technical Contact: Michael Bortolussi, ARC, (415) 694-6187

Evaluation of Voice-Activated Controls

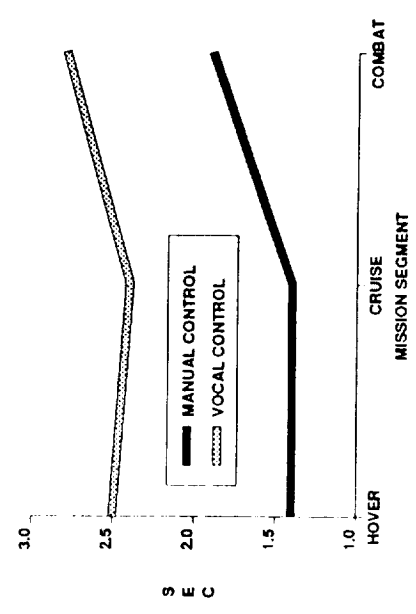
COUNTERMEASURE TASK: RATED WORK LOAD



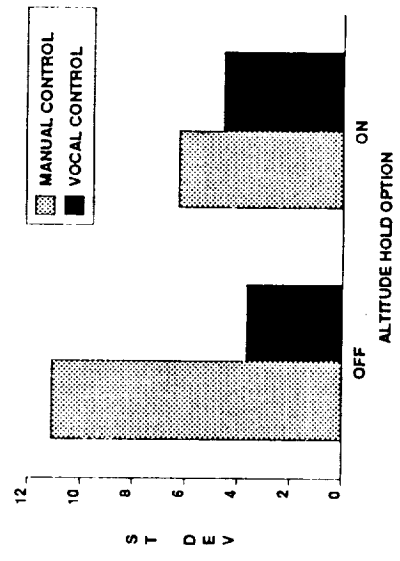
WEAPONS SELECTION TASK: RATED WORK LOAD



COUNTERMEASURE TASK: ACTIVATION LATENCY



HOVER STABILITY



Voice I/O Helicopter Flight System Experiments

A highly flexible and modifiable automatic voice I/O system has been developed for flight research at ARC. It will be used to collect inflight data as part of a cooperative U.S. Army/NASA aircraft system research program. The main purpose of the system is to provide the capability for comprehensive experimental evaluations of the reliability and effectiveness of speech control and display technology over a wide variety of flight conditions. Initially, the system will be flown and evaluated in a TH-15 Cobra helicopter.

The overall U.S. Army/NASA research program consists of five evolutionary phases. Phase one consists of flight system development that will produce two complete voice I/O flight systems; one will be installed and checked-out in the aircraft, and the other will be used in the laboratory as a developmental and ground-testing system. Phase two consists of ground testing of the airborne and laboratory systems to ensure their functional equivalence and to achieve essential preflight experimental capabilities. Phase three will be a basic airborne-platform evaluation in which the voice I/O flight system will function independently from other onboard avionics systems. Such factors as maneuver and noise effects and the influence of prompted versus unprompted speech will be evaluated. Phase four consists of functional evaluations of the voice I/O system, integrated with other onboard avionics systems, to assess voice flight-data request and display capabilities in flight. Phase five will use the voice I/O system to control onboard avionics, such as radios and selected display elements of a pilot night vision system (PNVS), and to evaluate techniques to provide intelligent interaction with the machine. The objectives of this program include the development of a general-purpose, flexible voice I/O research capability for the Cobra helicopter, the collection of objective system performance, pilot evaluation, and design and handling qualities data, and the comparative evaluations of speech technology concepts for meeting various helicopter mission requirements.

In this overall program, NASA researchers will evaluate issues related to speech control (input), speech display (output), and speech I/O. Speech input research will be performed to evaluate structured prompting and sequence effects, syntax techniques for vocabulary subset selection, and adaptive techniques to maintain highly accurate speech recognition despite changes in the physical environment, such as noise and vibration, and in the presence of pilot stress and fatigue. Speech output research will evaluate the effects of message interruption and modification, simultaneous message output, and message redundancy and delay. Speech I/O research will evaluate overall system performance in relation to the use of specific voice I/O devices, speech-feedback techniques, pilot query and automated decision aids, and intelligent systems dialog techniques.

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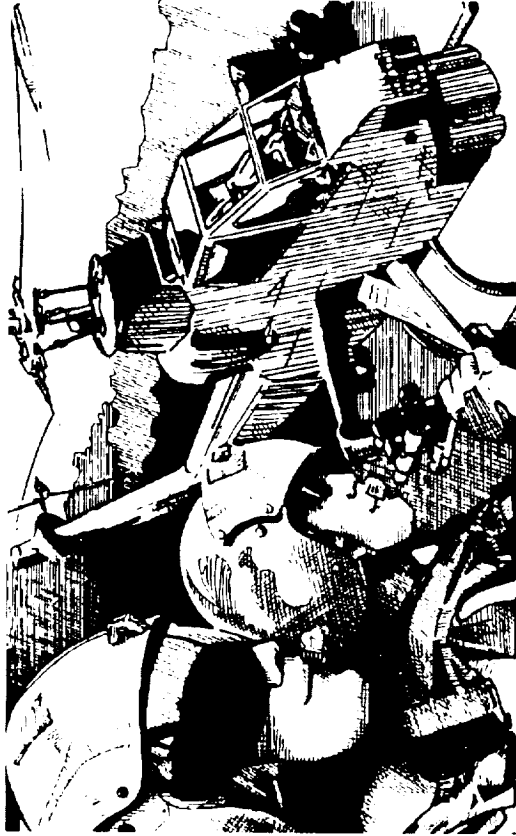
Voice I/O Helicopter Flight System Experiments

OBJECTIVES:

- SPEECH CONTROL (INPUT)
 - PROMPTING, SEQUENCE EFFECTS
 - SYNTAX TECHNIQUES
 - ADAPTATION TECHNIQUES (TO COUNTER NOISE AND STRESS)
- SPEECH DISPLAY (OUTPUT)
 - MESSAGE INTERRUPTION/MODIFICATION
 - SIMULTANEOUS MESSAGES
 - MESSAGE REDUNDANCY/DELAY
- INTERACTIVE MODE (I/O)
 - COMPARISON OF DEVICES
 - FEEDBACK TECHNIQUES
 - DECISION AIDING /DIALOG TECHNIQUES

APPROACH:

- CONDUCT FLIGHT RESEARCH IN TH-1S COBRA USING VOICE I/O SYSTEM DEVELOPED BY ARMY AND NASA
- USE CORRESPONDING LABORATORY SYSTEM FOR PRE-FLIGHT TESTING, EVALUATION OF CONCEPTS NOT YET READY FOR FLIGHT TEST



Information Management and Transfer

The effective management and transfer of information within the National Airspace System (NAS) is critical to a safe and efficient air transportation system. Future NAS operations will require flight-deck information management systems designed for optimal transfer of airborne, ground, and satellite information to aircrews. Information management principles are required which define the information needed, when it is needed, and in what form it should be provided.

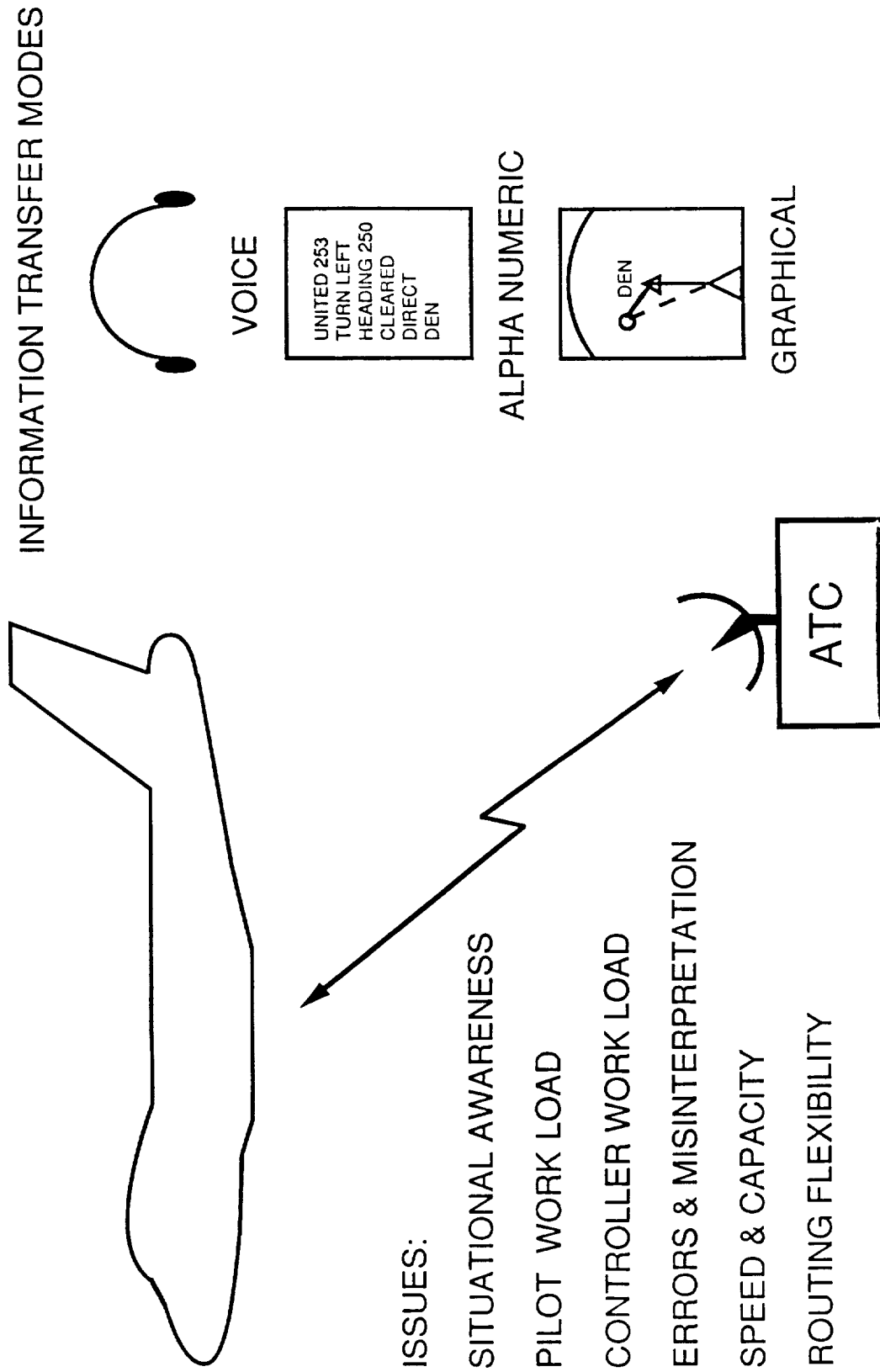
The Aviation Systems Research Branch (Code FLS) has an ongoing research program to develop design principles for advanced flight-deck information management systems and computer-aided design technology to facilitate the integration of new information technology. As air-to-ground and airborne information transfers become a part of this research, aircraft-ATC integration in the future NAS will benefit from this effort. In order to attain the program goals by fiscal year 1992, a multifaceted approach has been undertaken. This approach includes the development of methodology for quantifying aircrew information requirements and information-processing capacity during all flight phases, the identification of current operational problems that could be eliminated by improved system design, the development and evaluation of prototypical information management systems, the development of part-system simulation technology as a low-cost design and evaluation tool, and the development of computer-aided design technology based upon information management principles.

During fiscal year 1988 a number of efforts were successfully completed in support of the program objectives. A test for quantifying aircrew information requirements and methods for deriving information load was developed. Analyses of the Aviation Safety Reporting System (ASRS)'s air-ground information transfer incidents were completed. In support of advanced communication management system development, linguistic analyses of communication problems resulting in accidents were completed, as was an aircrew survey of automation requirements of proposed data link communications. A grant to MIT was initiated to develop an optimal automated clearance delivery system for advanced aircraft. With specific regard to weather information management, a study to determine minimal information transfer requirements for ground-based terminal radar was completed, as was an analysis of ASRS weather-related incidents.

Future efforts planned in support of this program are the development and evaluation of alternative measures of aircrew information load and the development of part-systems simulation technology for use in computer-aided information system design. With regard to air-ground communication management, the development of an error-resistant data-link communications protocol is planned, as is the development of optimal interfaces for display-based communications systems. In weather information management, guidelines will be developed for flight-deck integration of ground-based weather information such as low-level wind shear and other severe weather avoidance information, and continued analyses of weather-related ASRS incidents.

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Transfer of ATC Clearance Amendments Via Data Link



Cockpit Procedures Monitor and Error-Tolerant Systems

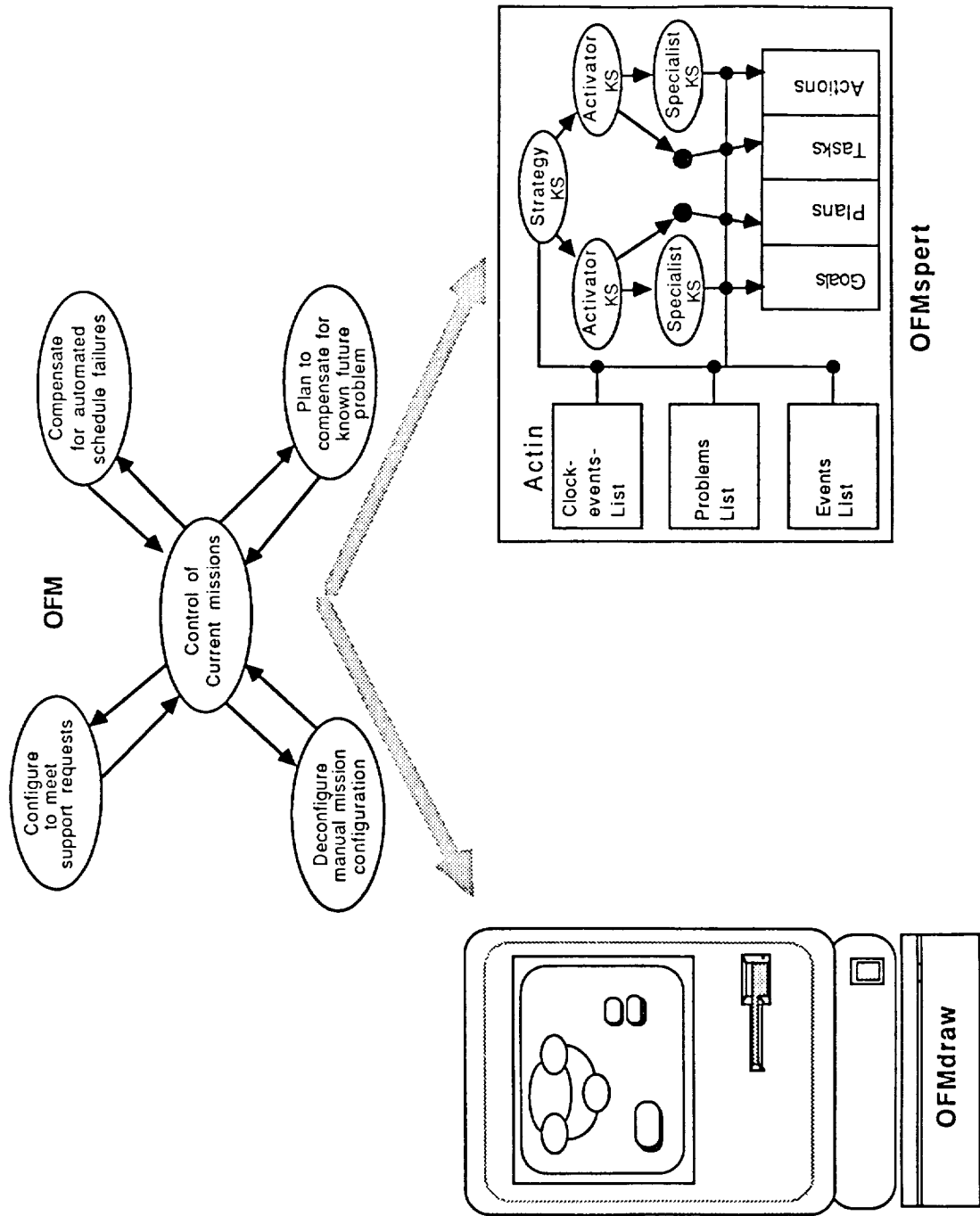
The objective of this research is to develop the technology necessary for the design of error-tolerant cockpits. A key feature of error-tolerant systems is that they incorporate a model of pilot behavior. The system uses this model to track pilot actions, to infer pilot intent, to detect unexpected actions, and to alert the crew to potential errors. In some sense, the goal is to develop an electronic check pilot that can intelligently monitor pilot activities.

A number of alternative ways to track operator activity and infer operator intent are being pursued. Techniques based on a rule-based script of flight phases and procedural actions, operator function models, and Bayesian temporal reasoning are being investigated. The first version of the script-based program was tested against protocol data from four 727 simulator flights. The program could detect procedural errors but its ability to account for pilot actions from procedures performed out of sequence was inadequate. A capability to explain unexpected actions by linking them to procedures that are nominally done or unstated is being added to the program to remedy this problem. Under a grant from Georgia Tech, an intent-inferencing system based on an operator function model was developed and tested on data from a satellite communications system with good results. Under a contract to Search Technology, a prototype for an intent-inferencing system based on Bayesian reasoning was developed. In the coming year, these three methods will be compared against data from the 727 simulator. An experiment to determine how check pilots detect procedural errors and infer pilot intent is also planned.

The technology developed for the cockpit procedures monitor will be used to develop an interactive cockpit display to aid pilots in executing procedures. In its initial version, this "smart checklist" will be a graphic display of the procedural script developed to track pilot actions. Modes of checklist operation will include passively monitoring pilot execution of procedures and automatically executing these procedures. Under a related SBIR contract, a procedure execution aid that can compose procedures that are appropriate for the current flight situation and equipment configuration will be developed and tested. These methodologies will be used to develop and evaluate in full-mission simulation a cockpit procedures monitor and a "smart checklist" in the Advanced Concepts Flight Simulator of the Man-Vehicle Systems Research Facility (MVSRF) at ARC.

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Operator Function Modeling - An Approach to Cognitive Task-Analysis in Supervisory Control



FAA Wind Shear Training Aid Automated Using Expert System to Explore the Use of Information Fusion to Improve the Detection of Wind Shear Threats

The objective of this study was to explore the fusion of different types of wind shear detection information with corroborating weather information to produce a more reliable estimate of the wind shear hazard than each of the wind shear detection methods could have produced independently. Such an increase in reliability could increase the probability of wind shear detection and reduce the number of nuisance warnings.

The FAA has developed a training aid to help pilots recognize and avoid wind shear. This training aid instructs the pilot to collect data from different weather sources and combine that information with their own visual and tactile information. The training aid provides an excellent example of information fusion. The first step toward the objective was to automate the information integration outlined in the training aid using an expert systems approach. Expert systems were chosen because the fusion structure developed within the training aid, or rules, mapped well to this approach. Princeton University was given a grant to explore this automation.

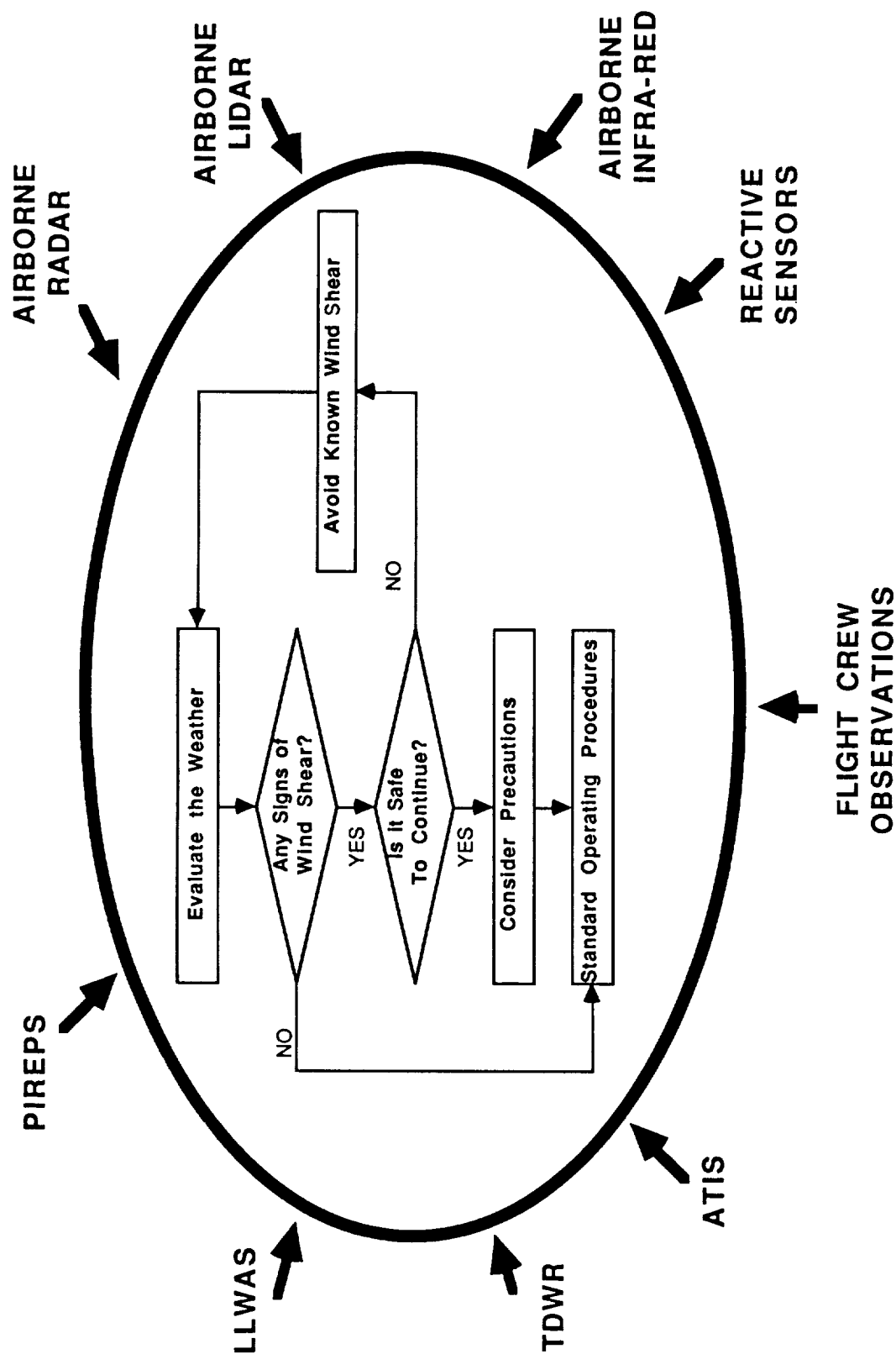
The grant produced a research-prototype wind shear recognition expert system that attempts to detect and classify wind shears based on various sources of input data, such as ATIS reports, LLWAS, air data, pilot visual sightings, and PIREPS. The prototype produces rudimentary assessment of the wind shear and rudimentary guidance, such as "High probability of wind shear" and "Abort takeoff". The prototype has 140 rules and is written in Common-Lisp on a Symbolics Lisp machine. The study also identified issues that will need to be explored such as the usefulness and availability of certain inputs, the effects of false alarms on flight crew confidence, and the user interface.

The prototype produced in this effort provides a basis for exploring the fusion of wind-shear-related information to provide a more complete and accurate assessment of hazardous wind shear. The lessons learned from this exploration can aid the development of systems which help reduce the number of inadvertent encounters with wind shear while minimizing the number of false/nuisance alarms. Such systems could lead to improved safety with a minimal impact on airport operational efficiency.

Future plans for this effort include the fusion of airborne forward-look sensor data into the detection process, an increased use of evidential reasoning within the prototype, an improved simulation of airport and aircraft for testing the prototype, and an assessment of aircraft safety versus pilot acceptance in the presence of false alarms and missed alarms.

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Explored the Use of Information Fusion to Improve the Detection of Wind Shear Threats Using Expert System Technology



Knowledge-Aided Display-Design (KADD) Concept Proved Viable

The primary objective of this research was to provide a computer-based, display-design system that enhanced the design process and its products by providing on-line assistance through an expert system with knowledge in human factors, ergonomics, and display formats. The interface was required to be graphical in nature and user friendly, thereby minimizing the need for special training or computer systems experience.

The KADD system was implemented on a graphics workstation through in-house and contractual efforts. A commercially available data base management library was used for the display-design bookkeeping chore, and the on-line, expert assistance was provided through the NASA-developed CLIPS, which managed the human-factors knowledge base. Because system probability was not considered in this proof-of-concept objective, considerable effort was saved by using these existing software modules.

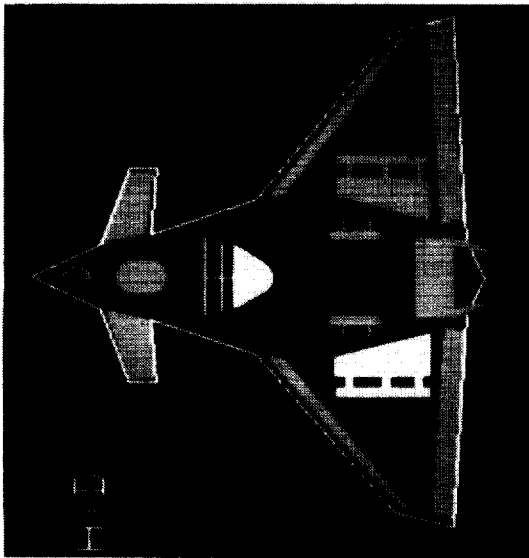
A unique, graphical interface to the KADD system was developed. This interface provided the designer with an intuitive, top-down mechanism for specifying his information requirements, as well as a linked-list representation of the relationship between the information requirements and the display being designed. Information requirements for an RPM gauge included the type of information and its required range and accuracy. Graphic objects, such as a gauge and an instrument, are being designed to convey this information. Information requirements may be linked to higher level functional requirements and still higher level task descriptions. This hierarchical approach to specifying the requirements for a particular display, or even an entire display panel, resulted in an effective means for matching the information required by the user with the display being designed.

KADD was presented to the DoD Human Factors Engineering Display-Design Subgroup in May 1988. The group's response was enthusiastic, noting that no other display-design tool combined a requirement-specification capability, an object-oriented graphics tool, and an expert system knowledgeable in display-design. The figure shows the broad variety of display formats that may be developed on KADD.

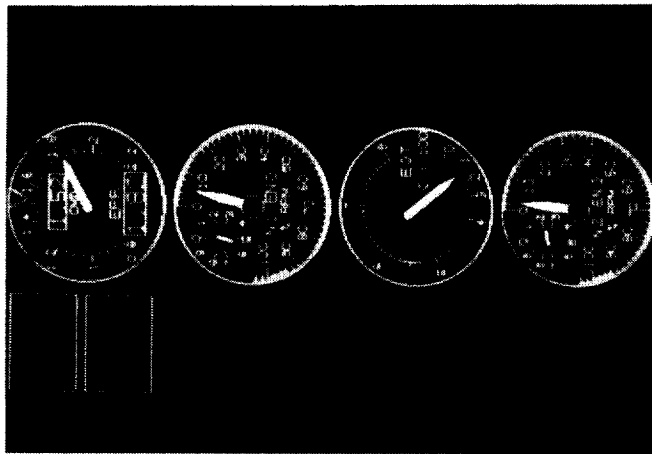
Although KADD has proved to be a viable concept, several enhancements are required to extend KADD beyond the proof-of-concept phase and to realize its full potential as a powerful, comprehensive display-design tool. To facilitate the continued development and effective transfer of this technology, contacts are being made with the DoD. Proposed developments include rehosting the software to a more powerful graphics workstation, engineering the knowledge base to provide broader, more intelligent feedback, providing an embedded simulation capability for display analysis, and providing generation of real-time code to speed the transition from the KADD environment to piloted simulator evaluations.

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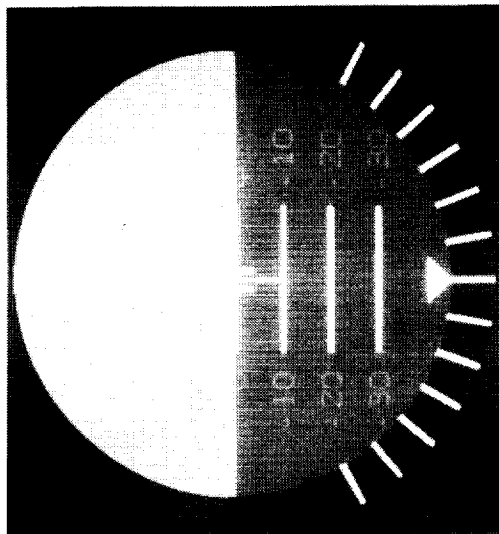
KADD Display Design Examples



SYSTEMS STATUS DISPLAY



DC-9 PARTIAL ENGINE PANEL



ATTITUDE DIRECTOR INDICATOR

Individual Crew Factors in Flight Operations

The current focus of this program is to assess the impact of fatigue and circadian rhythmicity on transport flight crew performance and to determine the contribution of factors associated with operational parameters, individual differences, and crew behavior. The approach is to combine limited laboratory and simulator research with field studies documenting the physiological and behavioral responses of aircrews operating in a variety of flight environments.

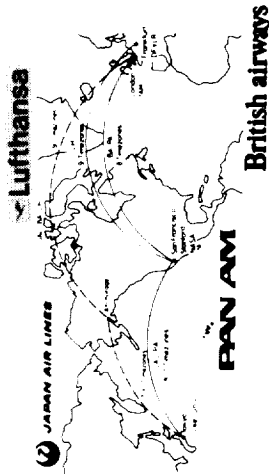
This is the first major attempt to study these issues objectively in both commercial and military flight crews. Increasing pressure for smaller and more productive crews requires a better understanding of how and why pilot performance can be degraded. Another factor is the planned introduction of highly automated aircraft into the long-haul arena. By fully understanding the impact and operation of these factors, it will be possible to improve flight safety and efficiency by developing guidelines for rulemaking and aircraft certification, by designing individual pilot-coping strategies, and by making operational recommendations to air carriers.

Research in fiscal year 1989 concentrated on field studies using cockpit observers and continuous physiological monitoring in flight operations such as Overnight Cargo Delivery (B727) and Nonaugmented Transpacific Patterns (B747). The Transpacific study uses continuous inflight monitoring of the crew's EEG to determine the effectiveness of preplanned cockpit rests in facilitating alertness during critical phases of flight. A cooperative program with research organizations and airlines in West Germany, the United Kingdom, and Japan enables the collection of crew EEG sleep-data during layovers on worldwide routes. A cooperative study of crew bunk sleep during extended long-range flights is the next research program planned for this international collaboration.

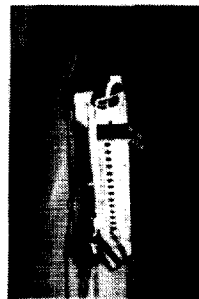
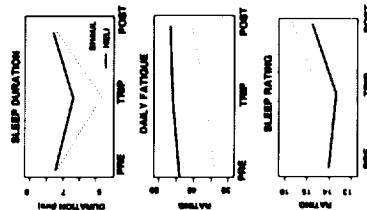
Data collection has been completed on long-haul crews, North Sea helicopter crews, and international polar crews. Technology transfer to the industry is occurring through interaction with the FAA aircraft certification teams, two U.S. Pacific carriers, and the development, with a U.S. manufacturer, of a crew alertness support device for long-haul glass cockpits. Plans have also been approved for a full-mission long-haul simulation study scheduled to have been initiated in the fall of 1989.

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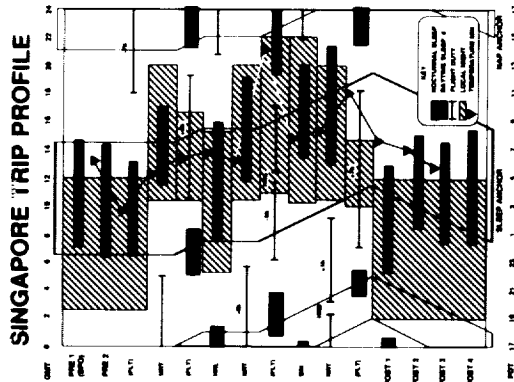
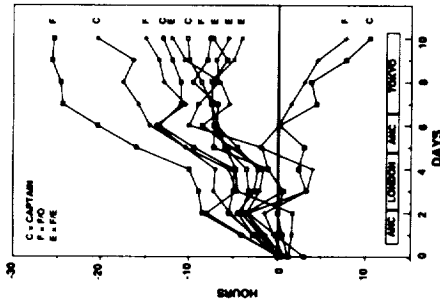
Individual Crew Factors in Flight Operations



HELICOPTER AND SHORT-HAUL PILOT POPULATION COMPARISONS



POLAR ROUTES: CUMULATIVE SLEEP LOSS



FINDINGS

LONG-HAUL OPERATIONS

- INT'L COOPERATIVE POLAR ROUTE EEG STUDY - OUTBOUND DIRECTION CRUCIAL (EASTWARD WORSE)
- LARGE INDIVIDUAL DIFFERENCES IN SLEEP LOSS - DESIGN/OPS IMPLICATIONS FOR 2-PERSON COCKPITS
- SCIENTIFIC SCHEDULING GUIDELINES DEVELOPED

OVERNIGHT CARGO

- CAN PROVIDE UNIQUE INSIGHTS INTO CIRCADIAN DISRUPTION OF FLIGHT CREWS

N. SEA HELICOPTERS

- DAILY SLEEP LOSS SIMILAR TO SHORT-HAUL BUT POORER SLEEP AND GREATER FATIGUE

PILOT SELECTION

- IMPROVED SELECTION STRATEGIES ARE FEASIBLE

Crew Factors in Aircrew Performance

The Crew Research and Space Human Factors Branch (FLC) has recently completed the Crew Composition Simulation to determine whether differing profiles of individual personality influence the crew performance process in aerospace operations. A total of 23 fully-qualified B-727 crews completed a 1½ day full-mission simulation of aviation operations. Crews were contrasted by the personality profile of their captain. The three profiles identified were Positive Instrumental/Expressive (IE+), Negative Instrumental (I-), and Negative Expressive (Ec-). The impact of the Captain's Personality Profile was assessed along with Expert Ratings, Crew Errors, and Aircraft Handling Parameters. Statistical analyses revealed that crews led by captains fitting the IE+ profile showed consistently effective performance, I- captains led crews who were ineffective on the first day but highly effective on the second, suggesting a familiarity effect, and Ec- captains led consistently less effective crews.

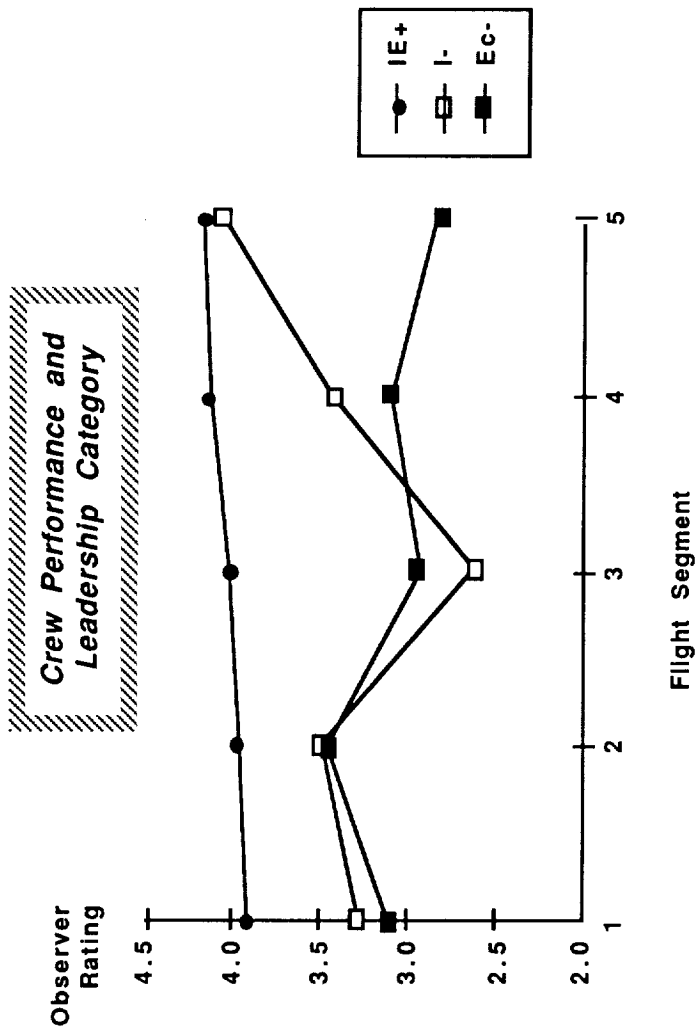
The study was initiated to determine whether personality is an important variable affecting group performance. The results presented here clearly suggest that the personality of a crew leader has a significant impact on group performance and is not to be considered trivial, and selection approaches should be seriously and carefully considered.

The more traditional approaches to the study of communication have typically failed to consider the fundamental interactive and sequential organization of the communication process between individuals. Understanding these processes is critical to the prediction of overall crew performance because these are the mechanisms by which crewmembers coordinate their activities, relay information, and solve problems. The design of artificially intelligent machines that will interact efficiently with humans depends on accurate determinations of how humans efficiently communicate with each other. The FLC program has produced new techniques for analyzing sequential and interactive speech patterns. They are now being applied in both natural and high-fidelity simulated environments that are analogously related to space operations. Communication patterns that differentiate high-error crews from low-error crews have been identified, including the distinctive differences in their use of question-answer and command-acknowledgement sequences as well as the differences in the relative rates of overall communication and nonresponse. At higher levels of analysis, it has also been found that the degree of homogeneity in speech patterns is greater for low-error crews while high-error crews show greater heterogeneity and less predictable forms of speech response.

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Crew Composition Simulation Performance Ratings

Personality profile of captain significantly impacts crew effectiveness:



- Crews led by captains fitting a positive Instrumental and Expressive profile (IE+) show consistently effective performance
- Negative Instrumental (I-) captains led crews who were ineffective on the first day, but highly effective on the second, suggesting a familiarity effect
- Negative Expressive (Ec-) captains led consistently less effective crews

Traffic-Alert Collision Avoidance System (TCAS)

The Traffic-Alert Collision Avoidance System (TCAS) is a stand-alone system that can detect the presence of any transponder-equipped aircraft within a prescribed envelope around a TCAS-equipped aircraft. TCAS can provide the pilot with a visual display showing the relative position, distance, and altitude of other aircraft. TCAS evaluates the closure rates and flight geometry of other aircraft relative to itself. If TCAS calculates that a collision threat exists, it will issue visual and verbal maneuver commands to the pilot. TCAS can "see" other aircraft even though the pilot may not be able to, such as in conditions of reduced visibility or high work load.

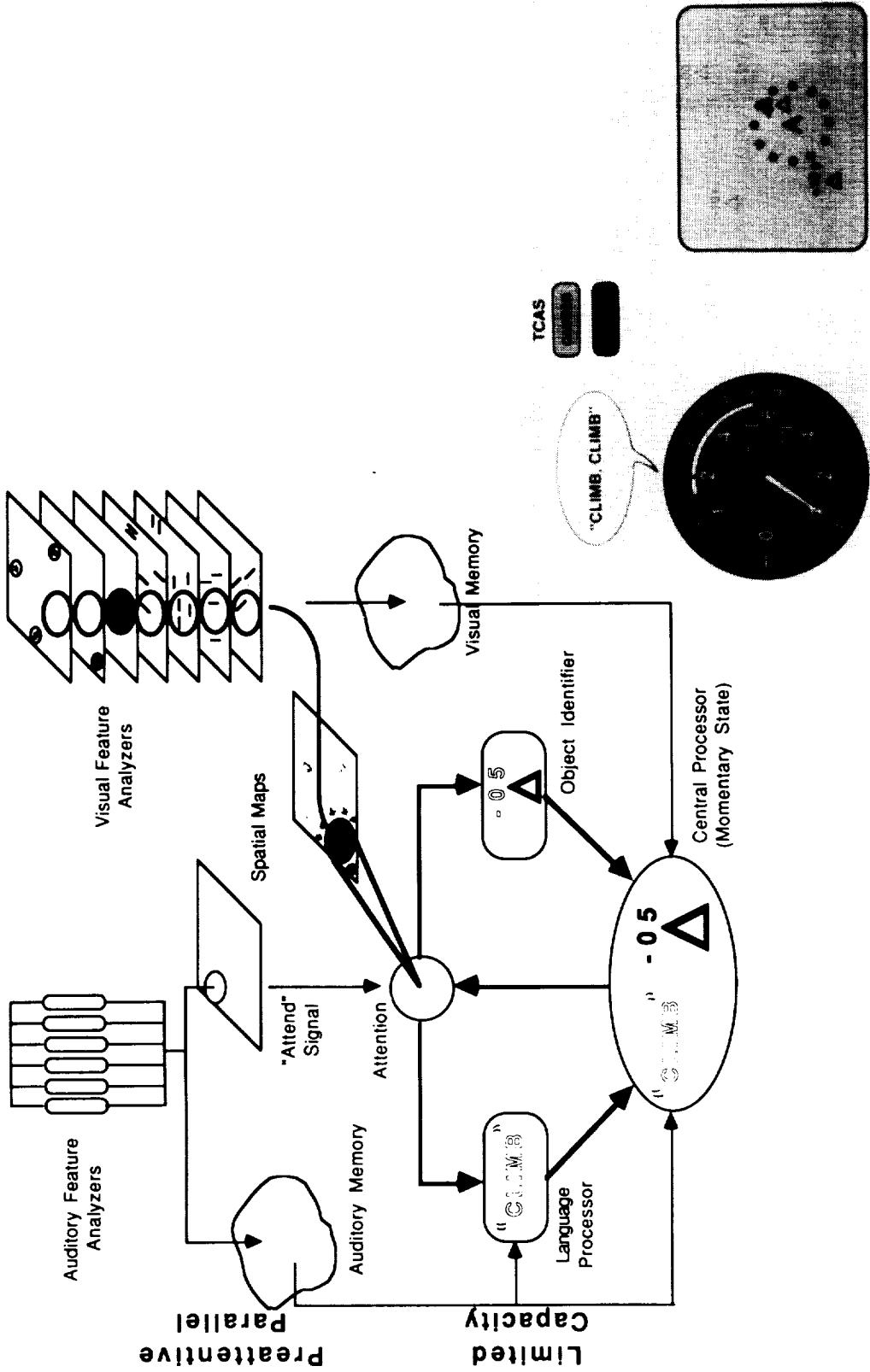
The aviation industry looks to ARC for guidance in evaluating the many human-factors issues. These include pilot interpretation of the information that TCAS makes available, pilot acceptance of the display format chosen by the manufacturers, pilot willingness to trust a system that commands him sometimes to make abrupt, evasive maneuvers due to unseen traffic, and pilot response time and success rate. System configuration changes introduced by industry and the integration of TCAS into the routine operating environment already existing in the cockpit are additional issues requiring evaluation.

ARC has conducted TCAS experiments using currently working airline crews flying typical airline flights to both terminal metropolitan destinations and outlying airports. These experiments explored TCAS with part-time and full-time traffic display as well as those with no traffic display; just maneuver information. Pilot performance with and without target areas displayed on the vertical speed indicator and pilot execution of the commanded maneuvers in different aircraft performance regimes were also explored. Two of the nation's major airlines currently have a limited number of TCAS-equipped aircraft operating on routine daily flights within the national airspace system.

Future research now planned will explore the optimization of TCAS maneuver guidance for the "glass cockpit," the combination of traffic with navigational information, and the optimization of voice command vocabulary to elicit proper pilot response.

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Traffic-Alert Collision Avoidance System (TCAS)



Computational Human Engineering Research

The Army-NASA Aircrew/Aircraft Integration (A³I) project is a joint Army and NASA research effort to produce a Human Factors-Computer Aided Engineering (HF-CAE) system called MIDAS (Man-machine Integration Design and Analysis System). The project's goal is to produce a human-factors engineering tool to assist design engineers in the conceptual phase of rotorcraft cockpit development and to anticipate crew-training requirements. The system provides designers with interactive, analytic, and graphical tools which permit early integration and visualization of human engineering principles.

Seventy to eighty percent of the life-cycle cost of an aircraft is determined in the concept design phase. After hardware is built, mistakes are hard to correct and concepts are difficult to modify. Engineers responsible for developing crew-training simulators and instructional systems currently begin work after the cockpit is built and it is too late to impact its design. The HF-CAE tools give designers an opportunity to see it before they build it, to ask "what if" questions about all aspects of crew performance including training, and to correct problems early. The current MIDAS system is focused on helicopters, but it is generic and permits generalization to other vehicles.

The MIDAS HF-CAE system is similar in concept to computational tools such as finite-element stress analysis and computational fluid dynamics which are used to improve designs and reduce costs. The results of the computational analysis are presented visually. The MIDAS uses models of human performance and a computational simulation of manned flight to evaluate the cockpit design. The results are presented graphically and visually to the design engineers, often as a computer animation of manned flight.

The major elements of the MIDAS system are an automated mission editor, a designer's simulation workbench including aircraft dynamics and guidance models, human behavior/performance models, system function models, and work load models [from rotorcraft Human Factors Research Branch], training requirements models, and three-dimensional CAD utilities for cockpit layout, instruments, and controls. Other elements include an anthropometric pilot model (graphic manikin), a designer's data, information, and analysis center, and a simulation and integration executive control system.

Three major phases of development have been completed in this project which began in Fall 1984. The target date for a full prototype system is 1994. The current phase focused on the expansion of several elements of the system and was demonstrated during the period of November 1988 to February 1989. The National Research Council's 2-year pilot performance model study is complete and has been published as "Human Performance Models for Computer Aided Engineering" (March 1989). Two applied models of visibility and legibility are planned for inclusion in the system in the next phase.

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Lower Pilot Stress Indicated by Heart-Rate Measures for Stereo Pictorial Landing-Approach Displays

Advances in technology have brought about numerous possibilities for the display of information to pilots in new, integrated display formats with potential for improving situational awareness and pilot/vehicle performance. One potential advance in piloted displays is the presentation of pictorial information using stereopsis cuing. The objective of this research, undertaken as part of a larger piloted study on pilot/vehicle performance effects, was to determine if the use of stereopsis in a pictorial landing-approach display would result in a reduction of pilot stress.

The study was designed to show the effects of stereopsis cuing upon heart-rate measures, because these measures have been demonstrated by LaRC researchers and others to be indicative of pilot stress. Six USAF pilots flew 24 transport-aircraft landing approaches each in Langley's Visual/Motion Simulator. The pilots were instrumented with EKG electrodes to record their inter-beat-intervals, and the data were sampled and stored for conversion to heart-rate data.

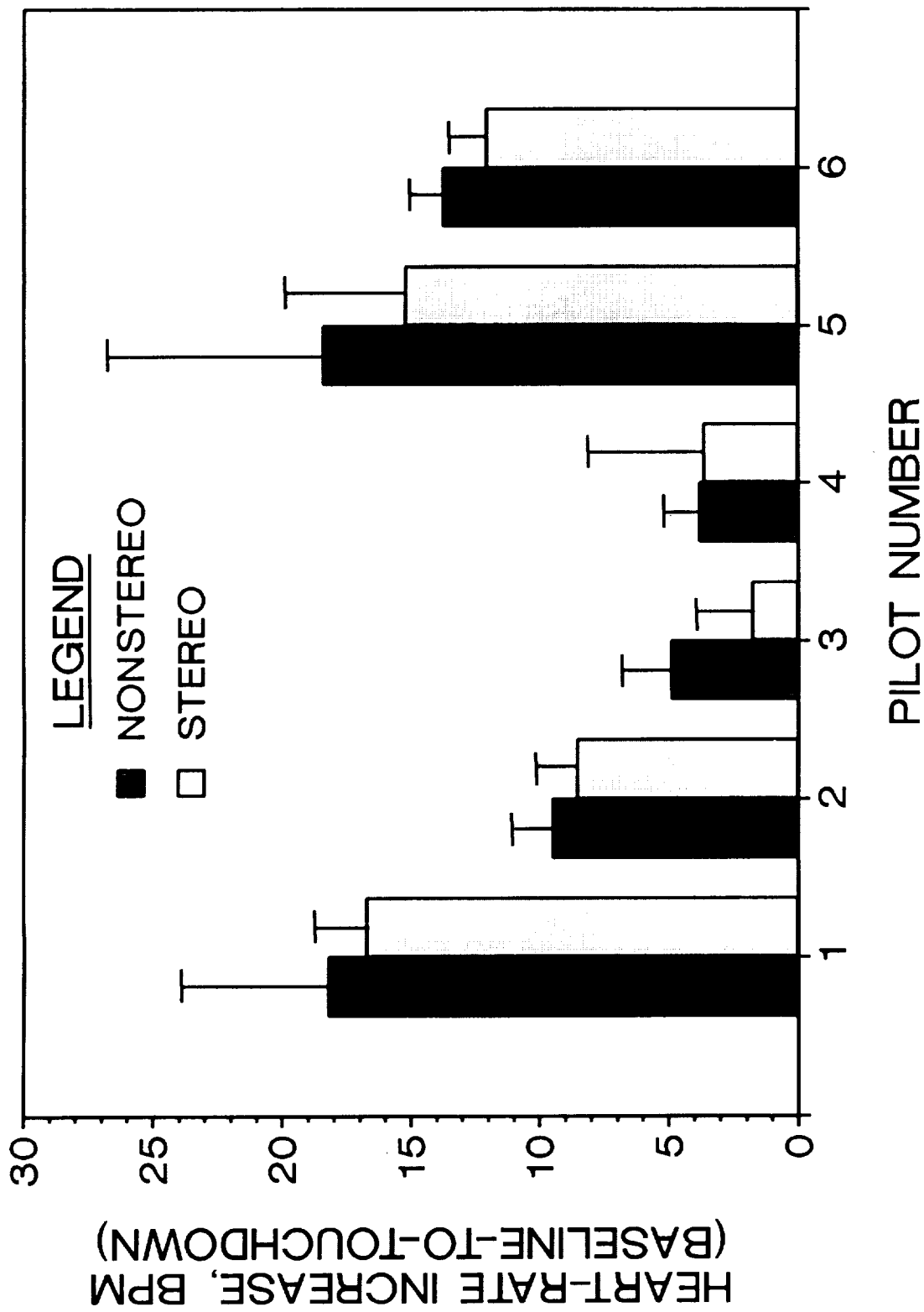
The following example represents the type of heart-rate time history acquired throughout the runs. At the beginning of the run, the pilot had a level heart rate until the introduction of winds 36 sec into the approach. This heart rate was used as the baseline heart rate. The heart rate typically increased throughout the approach because of the increased amount of stress caused by the winds, followed by the curved, descending, decelerating approach, then by the flare-to-landing on the runway. The peak heart rate was measured at touchdown. The heart-rate measure used to indicate the level of stress of the run was the difference in the touchdown heart rate and the baseline heart rate. The average heart-rate increase for all pilots was less when the stereopsis cues were present ($p < 0.01$) than when they were not present. The average heart-rate increase for all pilots was 11.4 beats/min for nonstereo presentations, but only 9.7 beats/min for stereo presentations. The figure shows the mean heart-rate increase, as well as the standard deviation of heart-rate increase, for individual pilots using the nonstereo/stereo displays.

The results indicate that stereopsis cues can reduce the amount of stress imposed upon pilots using a pictorial display for the tasks involved when in a curved, decelerating landing approach. They show that the increase in heart rate between baseline and touchdown is a far better physiological measure to use than heart rate at touchdown, because it is tolerant of the variability between subjects.

Further evaluations using stereopsis cues will be performed to determine which type of approach-path design in a pictorial display will produce the least amount of stress upon the pilot. Future studies employing the heart-rate measure will be designed so that there is a portion of the task that can be used as a baseline or as a standard task load to compare against heart-rate increases induced by the other tasks.

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Comparison of Pilot's Heart-Rate Responses to a Nonstereo/Stereo Landing-Approach Display



Comparison of Cobra Communications Control Configurations

In order to select a different radio in the Cobra AH-1 helicopter, pilots must remove one hand from the controls. This has the potential for impairing flight safety during critical mission phases. A study was conducted to investigate the feasibility of using a four-position switch mounted on the hand-grip of the cyclic control that would allow pilots to reconfigure their radios without removing their hands from the control. Pilot performance and work load with the proposed and present configurations were compared in ground and flight tests in a Cobra in collaboration with the U.S. Army Aeroflightdynamics Directorate. Researchers were able to take advantage of existing methodologies to conduct the test in a timely manner.

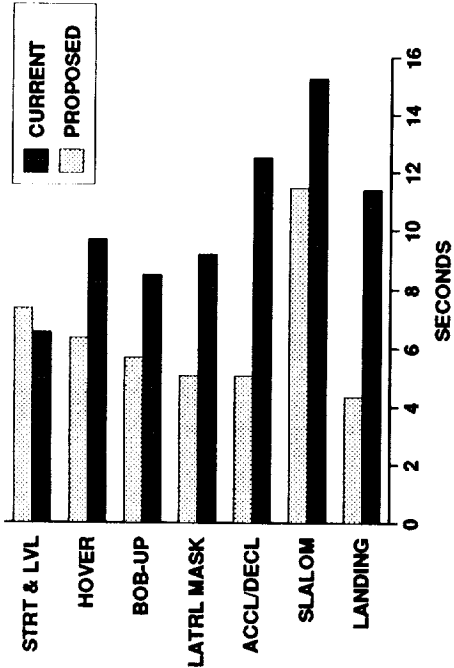
A significant reduction in pilot work load was found for the proposed configuration in ground tests and during every type of maneuver tested in flight. For some flight tasks, such as landing, where continuous use of the cyclic and collective controls is required, rated work load was more than twice as high with the current configuration than it was with the proposed modification. Flights with the proposed configuration were also given better Cooper-Harper Handling Qualities Ratings than were flights with the current configuration. The time that it took the pilots to change radio selections was recorded from video tape recordings made in the cockpit during the flights. The radio selection time was almost twice as great when the pilots used the original configuration than when they used the modified configuration. In a tactical situation, this time savings, that was as great as 8 sec, could be critical to the flight crew.

The results of the study have been documented and presented to the U.S. Army Aviation Systems Command (AVSCOM). It is likely that the proposed modification will be adopted. A fleet-wide introduction of the proposed modification should result in a significant reduction in work load for Cobra pilots.

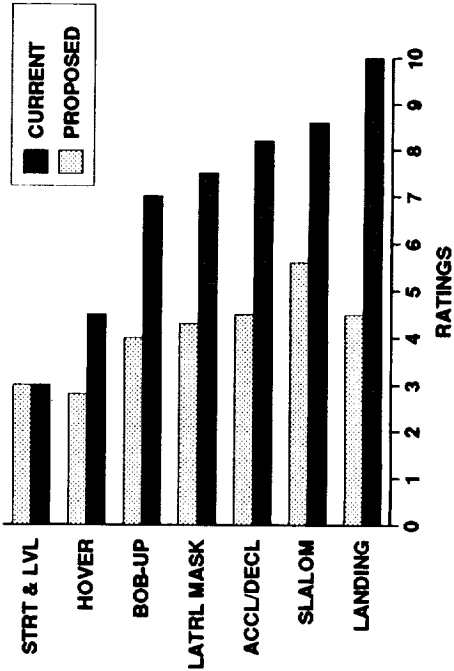
Technical Contact: R. Jay Shively, ARC, (415) 604-3665

Current Versus Proposed Radio-Selection Controls

RADIO SELECTION RESPONSE TIME



RATED WORK LOAD



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Cognitive Factors in Visual Attention

Research was initiated at the Technion to examine the cognitive and perceptual demands placed on helicopter pilots using helmet-mounted displays (HMD) of sensor imagery for low-level missions at night with reduced visibility. The goal is to establish guidelines for the use of monocular, binocular, and biocular HMD formats and propose alternative training methods to improve pilots' abilities to use such devices.

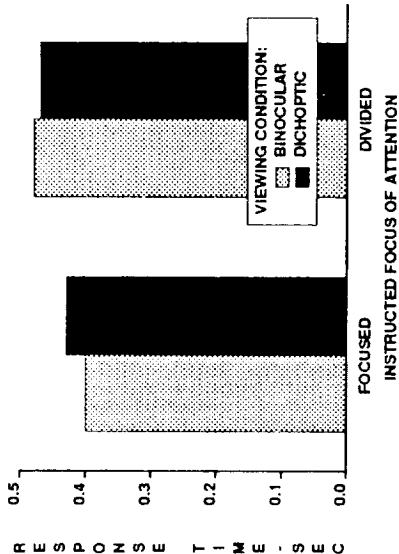
The first experiment contrasted dichoptic and binocular presentation by requiring subjects to judge which of two pairs of geometrical shapes were closer together. Binocular trials presented both pairs side by side while dichoptic trials presented different pairs to each eye. Subjects were instructed to either focus or divide their attention between the two visual fields. The results suggested that people can focus their attention on information presented to one eye or the other but that it is difficult for them to divide their attention between two different visual fields. It demonstrated the human ability to use two eyes as separate information channels and the importance of attention strategies for efficient information processing. The second experiment investigated the perception of global and local features of compound visual patterns, such as large letters like T or H composed of the same or different smaller letters, presented binocularly or dichoptically. Subjects were instructed on different trials to either focus, as in a search for targets at either the local or global level, or to divide their attention, as in a search for targets at both levels. Focused attention again resulted in faster reaction times and fewer errors than divided attention and there was no difference in performance between dichoptic and binocular viewing conditions. The third experiment compared performance with compound stimuli that also varied in size under focused or divided attention, with dichoptic or binocular viewing conditions. No performance difference was found between dichoptic and binocular presentation and performance was worse with divided than it was with focused attention. A performance advantage was found for large letters with divided attention.

These results suggest that people can process information presented independently to the right and left visual fields, at either global or local levels of detail, without a significant performance decrement. The most important factor seems to be whether focused attention or divided attention is required. The consistently worse performance with divided attention instructions demonstrated the important role of central processes in visual perception. In future research, the effects of interfering movement in the irrelevant visual field and foveal-versus-peripheral presentation of information in the relevant or irrelevant eye will be examined. Experiments will be performed in a motion-base simulator in which pilots will fly using a HMD while monitoring a panel-mounted CRT (time-sharing between a dynamic continuous task and a static discrete task). A second condition will present different dynamic visual displays to the two eyes: a narrow FOV display on the HMD and a projected out-the-window display. FOV, displaced viewpoints, and image brightness will be manipulated to simulate inflight conditions with helmet-mounted displays.

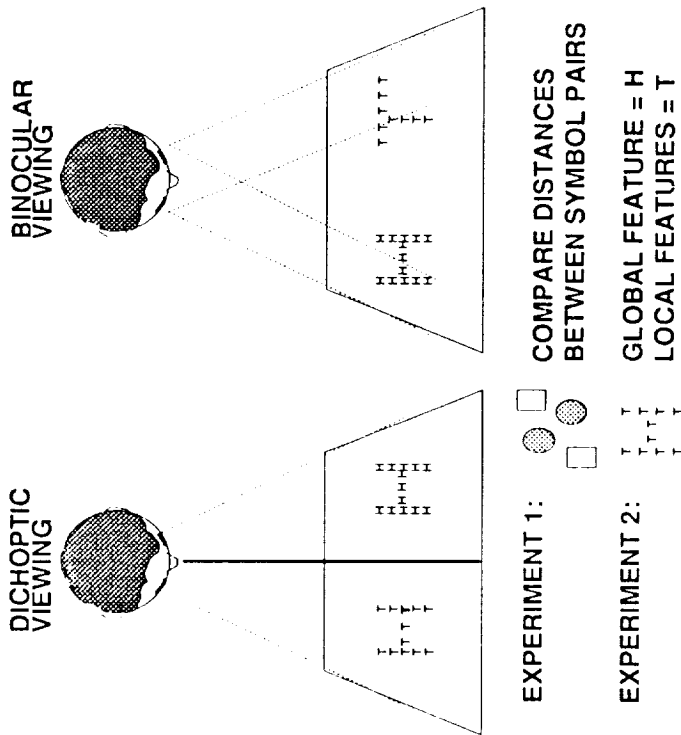
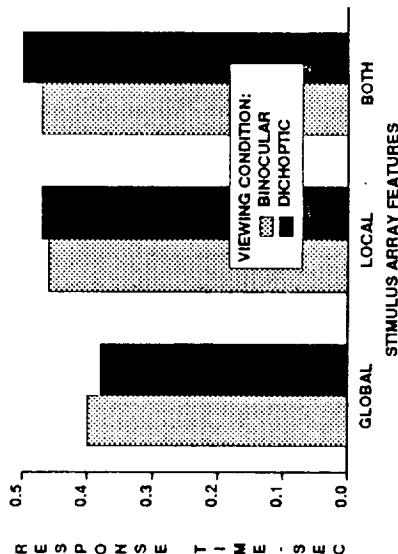
Technical Contact: David Foyle. ARC, (415) 694-3053

Cognitive Factors in Visual Attention

ATTENTION INSTRUCTION x VIEWING CONDITION



FEATURES EVALUATED x VIEWING CONDITION



Human Factors - Space

The objectives of the Space Human Factors Research and Technology Program are to provide a technology base for intelligent operator interfaces, especially with autonomous subsystems, and to develop a new generation of high-performance space suits, gloves, and tools/end effectors to meet the requirements of advanced space missions. The technology base is intended to provide increased productivity, efficiency, and safety in complex manned operations within automated onboard systems and extravehicular activity (EVA) environments.

Crew station research is the first of two major areas. Development of methods for the astronaut to supervise, monitor, and evaluate the performance of robotic systems, other space subsystems, and orbital vehicles are key areas of research. Fundamental understanding of the human visual and information integration capabilities provides a technical basis to develop mathematical, anthropometric, and graphical models of human interactions with space systems and equipment. A laser-based human body mapping system was obtained and accepted for use by the JSC. Considerable development of computational vision, a new technology subelement, was seen by the completion of basic algorithms of human vision for machine application. Development of advanced graphics and visual simulation methods was accomplished so that human performance under zero-gravity conditions at Space Station *Freedom* could be determined. Additional design criteria and guidelines were added to "Man System Integration Standard, NASA Standard 3000," as a result of tests of new human-computer interface tests for Space Station *Freedom*.

The second major area is the development of a new extravehicular activity (EVA) space suit, gloves, end effectors, and helmet-mounted displays. The AX-5 hard suit was tested and evaluated against a second new EVA suit, Mark III, which has both hard metal and fabric features. Both suits are designed to meet zero-prebreathe requirements for Space Shuttle and Space Station *Freedom* operations. Technology from both suits is expected to be used for Space Station *Freedom* EVA suit systems. An anthropomorphic master-slave arm and hand were completed this year. An important feature of this new technology is a force feedback capability whereby the user receives feedback of the proportional amount of force being applied by the robotic end effector to the object being grasped by the human user. The human factors research program tested new methods to display information on the space suit's visor. Astronaut control of information, while in EVA, was evaluated using both voice command and gaze command.

Emphasis in the Space Human Factors Research Program is placed on technology baseline studies and development of methods, techniques, and data to support productive and safe operations by the astronaut and crew as they interface with complex systems, advanced automation, and robotic assistants.

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Advanced Extravehicular Activity (EVA) Suit Technology

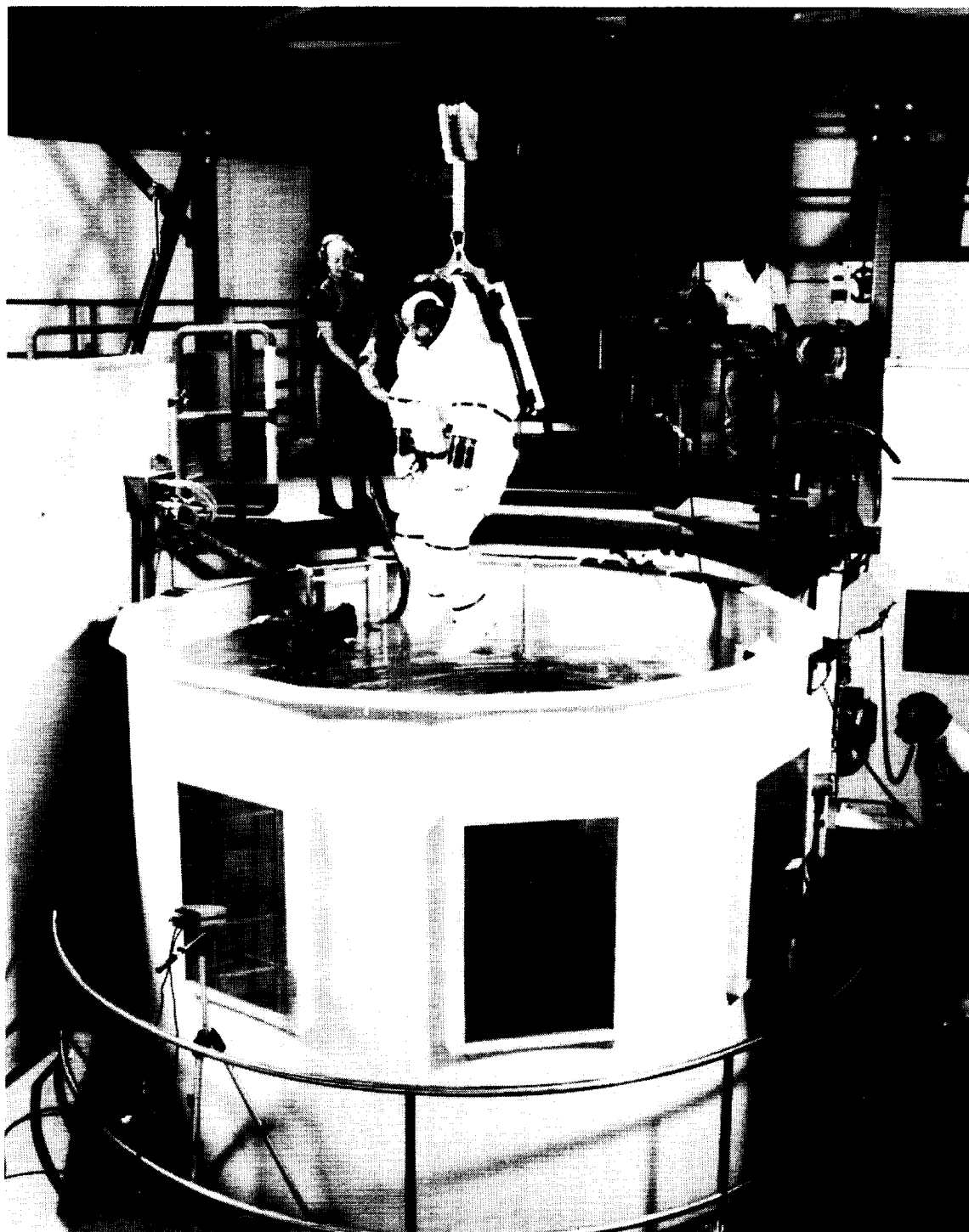
The ARC has an ongoing program to address EVA suit technology requirements for the Space Station. A product of this effort has been the development of the Ames AX-5 space suit. The overall objectives of this development effort have been to provide a high-mobility suit technology that eliminates the need for prebreathing, provides increased hardware and systems life, minimizes maintenance, provides increased hazard protection, and accommodates a large-population sizing capability.

As part of the overall evaluation process, a series of tests have been established at JSC to assess the performance of advanced suit concepts as compared to the current Space Shuttle EMU. These tests consist of mobility range comparisons, torque/force work capability, general workstation performance assessment, and the EASE/ACCESS structure assembly simulation.

In early 1988, tests of the AX-5's mobility and range of motion were completed in the JSC Weightless Environment Test Facility (WETF). Although the hard data of these tests have not yet been released by JSC, indications are that the AX-5 has considerably more mobility than the Space Shuttle EMU.

Currently, the AX-5 bearing assemblies are undergoing modification. Upon completion, tests were scheduled to be resumed in early 1989 at JSC to complete the test matrix. Component mobility, torque, and life cycle tests will be initiated at ARC to complete the performance assessment of the AX-5. Subsequent upgrades are anticipated and will be incorporated into the AX-5.

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Extravehicular Activity Suit

Current extravehicular activity (EVA) capabilities have evolved over the years and have been influenced primarily by zero-gravity operations. However, the hostile, partial gravity environments of the Moon and Mars present additional challenges. These challenges include enhanced suit/glove mobility; long-duration radiation protection; optimum physiological conditions for in-suit life support; efficient, low-weight heat rejection/life support systems, and lightweight, long-life contamination insensitive suit materials and components.

The JSC has initiated a technology program to address these mission-critical technology issues. The objectives of this program are to develop the analytical and hardware technologies necessary to allow humans to perform EVA productively and efficiently in the hostile environments of the Moon and Mars. This initial effort will concentrate on human requirements definition, emphasizing human factors; EVA systems integration modeling/analysis; EVA heat rejection modeling/analysis; atmosphere control subsystem modeling/analysis; and pressure suit technology, emphasizing suit materials and structures.

Accomplishments in fiscal year 1989 are described for each of these areas. In regard to the biomechanics of EVA, partial-g conditions have been simulated in the JSC Anthropometry and Biomechanics Lab for studies of locomotion. Treadmill studies, which measured EMGs of locomotion muscles, z-axis impact, two-dimensional motion, acceleration, and velocity, also were conducted. This study is preparatory for detailed analysis of locomotion in partial-g. In the area of EVA System Modeling/Analysis, mission design requirements of the advanced EVA System (EVAS) and the performance and system level input/output requirements of the enhanced EVAS analysis program have been defined. Progress has been made in establishing input/output requirements of advanced EVAS component analysis routines and in reviewing existing candidate components/subsystems for advanced EVAS applications. EVA Heat Rejection Modeling/Analysis accomplishments include a set of advanced heat rejection system (HRS) analysis program performance requirements that have been established. Identification of upgrades to the JSC in-house Interactive Thermal Design System (ITDS) model for modeling advanced HRS technologies has been completed. Identification of existing HRS component technologies to be modeled is in progress. In regard to EVA Atmosphere Control Modeling/Analysis, enhanced atmosphere control subsystem (ACS) analysis program performance requirements have been established. Identification of the existing ACS processes/components to be modeled using ASPEN is in progress. In the area of Pressure Suit Technology, a study is in progress with Albany International Research/ILC-Dover to investigate the use of lightweight materials (including composite layups, sandwich structures or advanced materials) for critical space suit structural component elements. A comprehensive study, conducted by Albany International/A. D. Little Corporation, to define materials and/or methods for dust protection and removal of dust contamination from the EVA suit during lunar and Mars surface operations is in progress.

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Extravehicular Activity Suit



Human-Computer Interaction

Human-computer interactions are a major method in which the crew interacts with the spacecraft. Improved interfaces can save man-hours and increase safety. Research in the JSC Human-Computer Interaction Laboratory (HCIL) focuses on research related to the design of a specific system, research related to the development of HCI performance models, and research related to the development of cognitive models applicable to HCI.

Research accomplished in the HCIL showed that presenting procedural information in a flowchart format resulted in lower error rates and faster step execution times but slower step access times than did a textual presentation. The causes were examined in an experiment that varied the spatial layout and the syntax. Both variables significantly affected the time needed to execute a procedure, with the spatial layout typical of a flowchart and a simple question and answer syntax producing superior performance. Step access time was affected only by the spatial layout. The information from these experiments is being used to develop a prototype system for the display of procedural information.

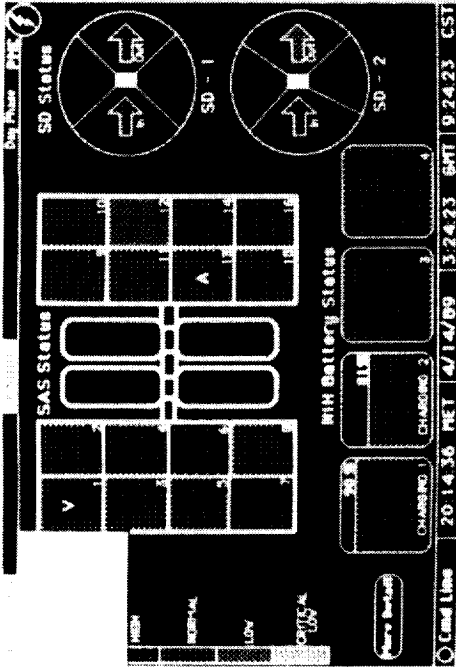
Work in this area centered around graphics and direct manipulation controls. Research on graphics indicates that users switch between two types of processing strategies with graphical displays: an arithmetic/look-up strategy and a perceptual/spatial strategy. Research on the representation of graphical information indicates that the representation of perceptual features (e.g., the axes; the points, lines, areas, and angles) is very strong relative to the representation of the quantitative and semantic information from a graph.

Research on direct manipulation controls was directed at modifying existing movement control models to accurately fit human-computer interactions and comparing movement control performance with the mouse, trackball, and post-mouse in 1 g and microgravity. The modeling effort focused on investigating the difference between a point-click sequence (which has been the basis for the dominant HCI model) and a point-drag sequence (which is a commonly used movement sequence with computer controls). The different movement sequences have profound effects on the application of such general movement control laws as Fitts Law. Response times with the trackball were less affected by the change from 1 g to 0 g.

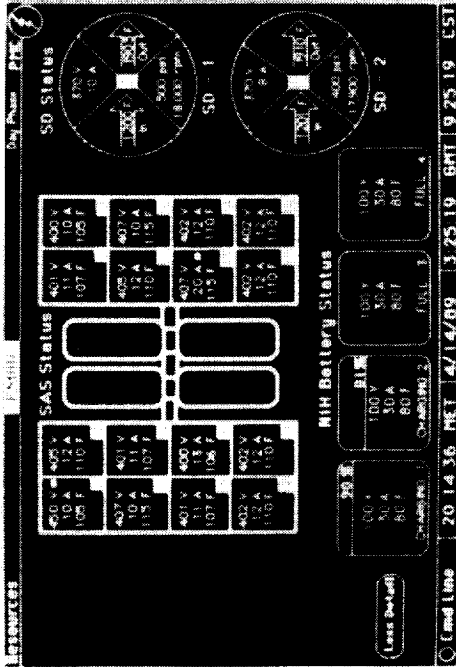
Research on cognitive model development compared the organization of declarative knowledge of two groups of human-computer interface experts (those with a human factors background and those with a software development background). The data, which are currently being analyzed, will be used to understand how to avoid miscommunication between the different disciplines involved in spacecraft HCI design. Research on the procedural knowledge of human factors and software development experts is currently under way. Other cognitive modeling research has centered around knowledge elicitation methods.

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Human-Computer Interaction

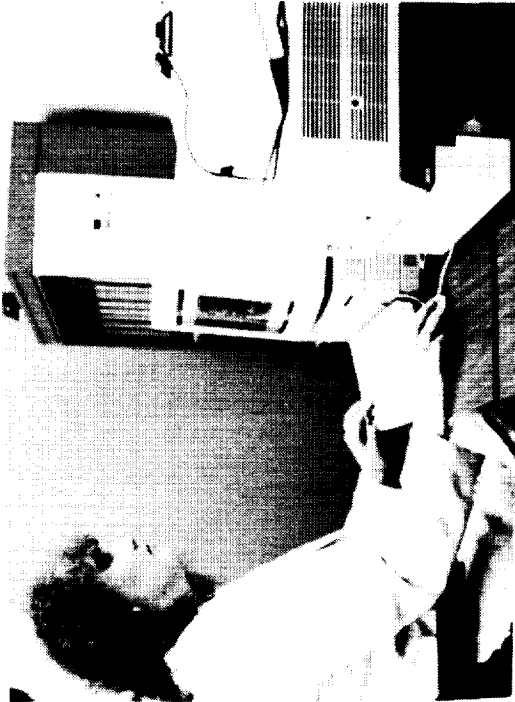


LOW-LEVEL DETAIL FOR SCANNING.
CLICK ON "MORE DETAIL" FOR DIG-
ITAL VALUES



DIGITAL VALUES DISPLAYED

- HUMAN-COMPUTER INTERFACE PROTOTYPES
APPLY RESULTS OF HCIL RESEARCH
- ANALYZE LEVEL OF DETAIL NEEDED BY USER
- ALLOW USER EASY ACCESS TO MORE DETAIL
- MAKE MORE IMPORTANT INFORMATION
MORE VISIBLE
- UNDERSTAND USER'S PREFERRED MODELS
OF INFORMATION MANAGEMENT



HUMAN-COMPUTER INTERACTIONS

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Human Interface With Intelligent Systems

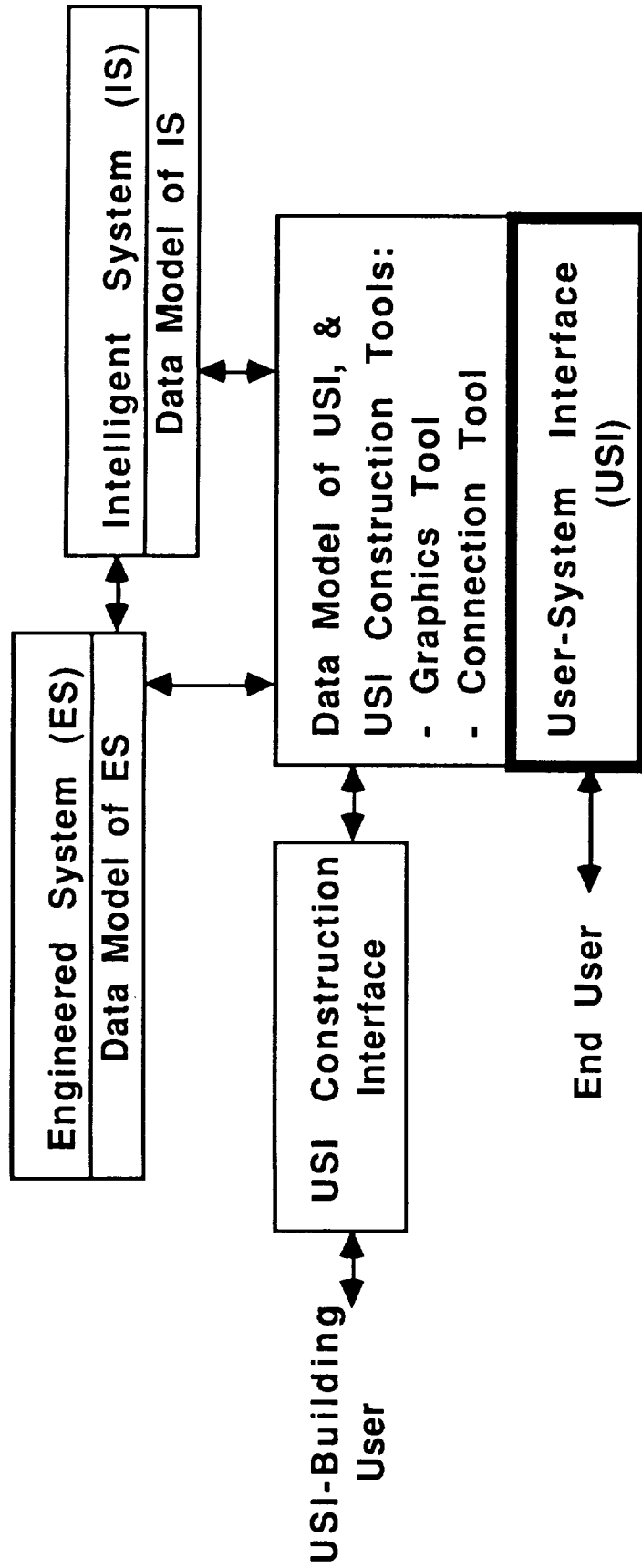
A multidisciplinary team from universities, industry, and government is contributing to a better understanding of the use of structure-function model-schematics and diagrams for human interfaces with intelligent fault-management systems to improve the human interface. A major product will be a prototype user-system interface construction tool and methodology. This tool and method will be used to design human interfaces, with the emphasis on use of graphics and on use of model information. This will be completed early in fiscal year 1990. Intelligent software assistants that support fault management of a space system can be more effective if they include a model of the structure and function of the managed system. This model can be used to understand the status of elements of the system and to analyze and explain system behavior. It can also serve as a basis for concrete interaction between operator and software.

The user-system interface construction tool and methodology are designed to support interface prototyping and design of intelligent systems for effective human interface. The software architecture is based on the use of data models of the information from engineered systems and intelligent systems. Although the main purpose of these data models is to provide communication layers between the systems and the human interface software, they can also be used to specify the information needed from the systems to support user understanding and intervention. Interfaces are constructed with a graphics tool for building displays, and a rule-based connection tool for tying the data models to the displays and managing the interface. In addition to the software, guidelines and a methodology have been defined for generating the data models and building interfaces. This software has been demonstrated using a fault-management scenario for a space station thermal-control system.

A significant accomplishment this year has been the development of a qualitative process model of a two-phase thermal-control system. This model integrates generic models for processes and components in thermal systems. These models include several optional types of detail that are controlled by explicit modeling assumptions. Thus, several types of analysis and explanation can be supported. A set of question-answering routines has been developed to accept queries, perform appropriate model analysis, and automatically generate natural-language explanations. Software has been developed to demonstrate use of this type of qualitative model to help set up analyses that include solving quantitative thermodynamics problems.

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Human Interface With Intelligent Systems



Man-Systems Integration Standards

The Man-Systems Integration Standards (MSIS) is a multivolume document which sets forth agency-wide standards for human-factors interface for spacecraft and space-related systems design. The MSIS was developed to compile, in a single document, relevant crew interface information that had previously been scattered in numerous documents and publications. Volume I contains generic considerations, requirements, and examples of implementation from previous space programs. Volume II contains all of the MSIS appendices. Volume III, currently in preparation, will be a handbook in which the basic Volume I information is condensed into a smaller, easier-to-carry volume. Program specific volumes have been developed under program auspices from the basic MSIS data base information. For example, Volume IV, specifically prepared for the Space Station *Freedom* (SSF) program, was approved as part of the SSF Program Definitions and Requirements Document and is imposed on all SSF elements and contractors. A draft of Volume V for the National Space Transportation System (NSTS) Man-Tended Payloads has been prepared and is under review. Plans are currently being made to produce a MSIS volume applicable to lunar and planetary surface environments.

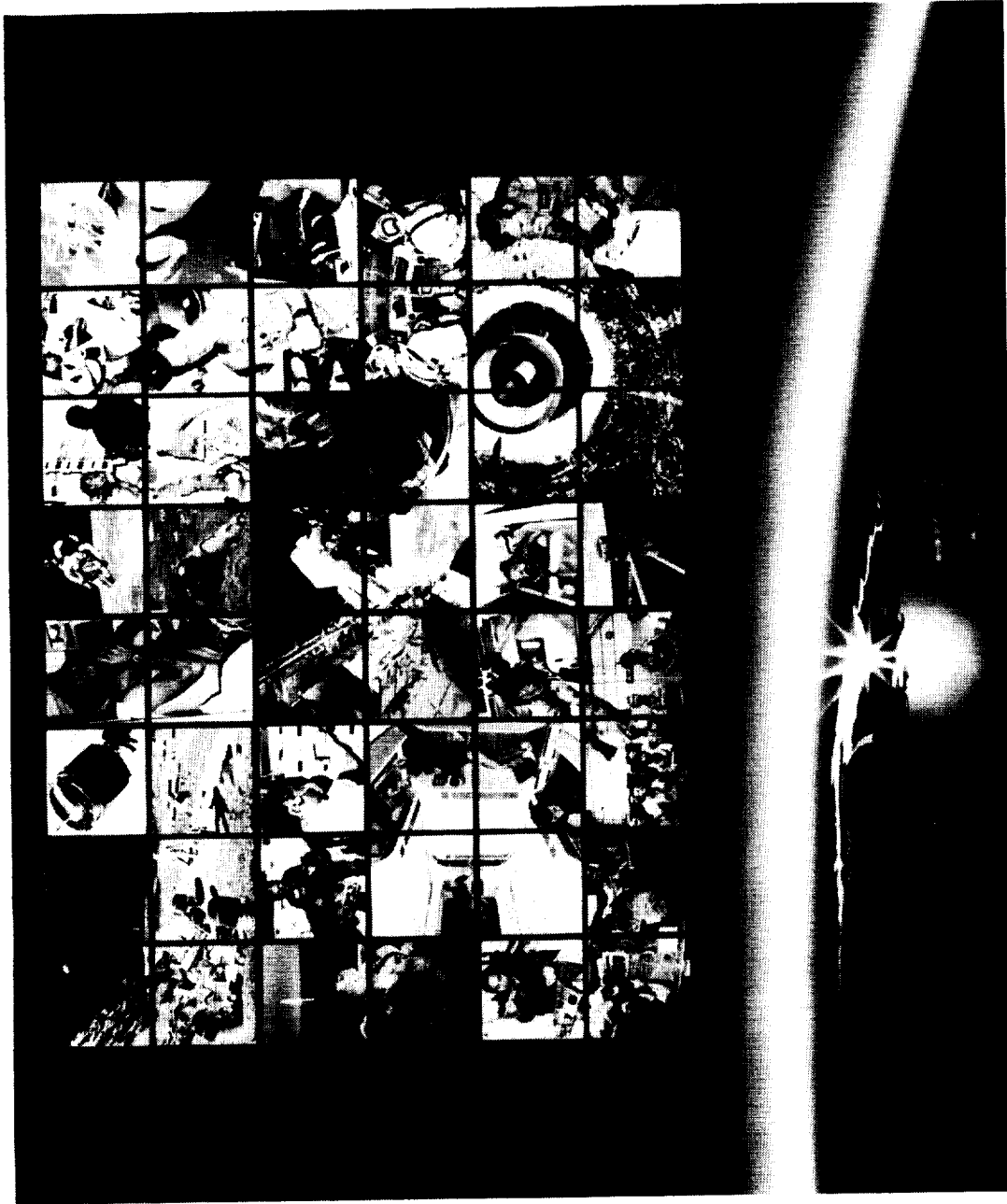
Accomplishments in 1989 include the completion of the Revision A draft based on last year's technical review of Volume I. A "mark-up" version of the document showing the change, original wording and applicable comments was created to facilitate review by the Technical Screening Panel (TSP) experts who determined what information should be included in the next revision to this volume. The draft of Revision A to both Volumes I and II was planned for release to an intercenter MSIS steering committee for final approval, and then for release to the approximately 1500 users.

The MSIS data base is also being converted to dBase IV software from the RBase 5000 in which it currently resides. This new data base will allow closer integration between the information in the data base. The desktop publishing system will allow users to access the data base without the need to supply their own software and presents users with a much friendlier interface. User-listing and change-tracking data bases have also been developed using the dBase IV software.

The next technical review of Volume I will be held next year after the Revision A has been in the hands of users for at least 6 months.

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Man-Systems Integration Standards



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Strength and Motion Modeling

The capability to visualize astronaut motion in 0 g is essential to human factors engineers for determining layouts, locations of restraints, and traffic patterns in spacecraft. It is also important for ascertaining if a certain operation can be performed in the designated location, for determining clearances and reachability, and for understanding the full field of view of an unrestrained astronaut in some spacecraft modules. The ability to generate animations almost automatically has been developed and has been employed by both the Shuttle and Space Station *Freedom* programs to answer these questions.

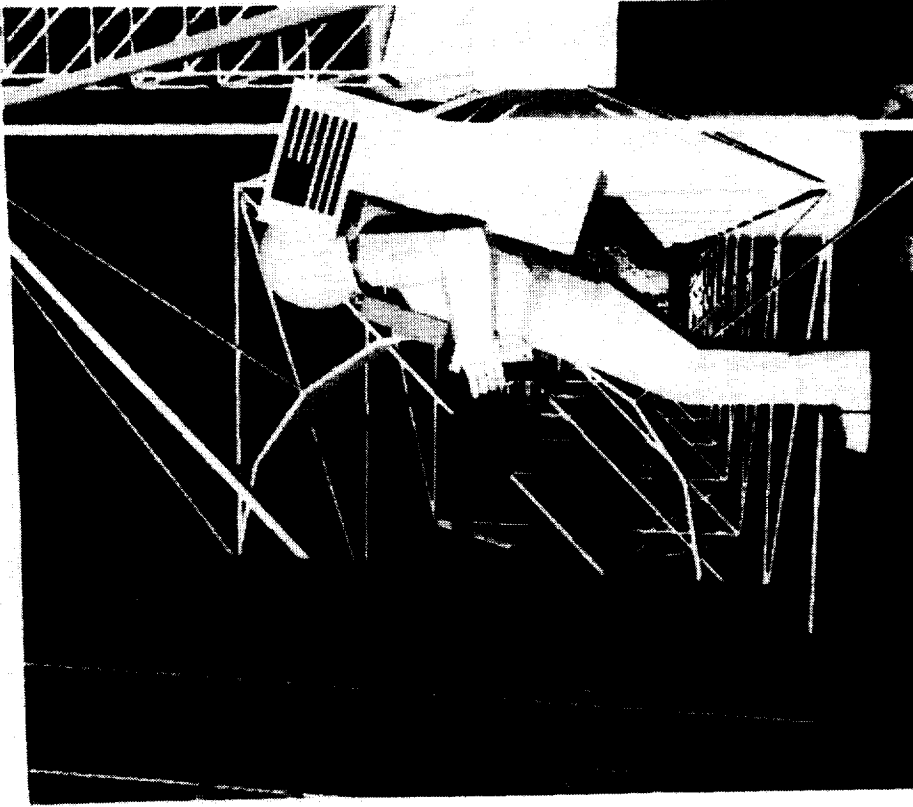
Using previously developed software, figures of an appropriate size, which can be specified as a percentile such as fifth percentile female or as an absolute height, are positioned in the 0-g neutral body posture in the desired workspace. The analyst then specifies a desired body position in terms of which points in the workspace are to be touched by which body parts. For example, the right foot should be in a foot restraint and the right hand should be on the translational hand controller. Software then redraws the body so that those constraints are met, if possible, and produces a message giving the "miss distance" if the position is not possible for that size individual. As a result of this year's work, this image can then be saved as a "key frame." After the first key frame is saved, a second one representing a later point time is created in the same way. Typically, key frames are created whenever motion starts, stops, or changes direction. After the key frames have been drawn, the software smoothly interpolates joint motion to generate intermediate frames to produce an animation with natural-seeming movement of the body.

The Space Station *Freedom* Program used this animation technique to produce an animation illustrating the removal of a rack from the logistics module by two crew members, its translation through nodes and modules, and finally its placement in the lab module. This animation identified locations where handholds or foot restraints are necessary to perform such an act. The figure shows two key frames that were used in studying whether an astronaut could perform an EVA module changeout with a tool of a specified design when in a confined area. The results showed that there was just enough clearance to make it possible, given the postulated sizes of the suit and tool. The Crew-Equipment Translation Aid was also studied, and a design problem was identified by use of reach algorithms and animation.

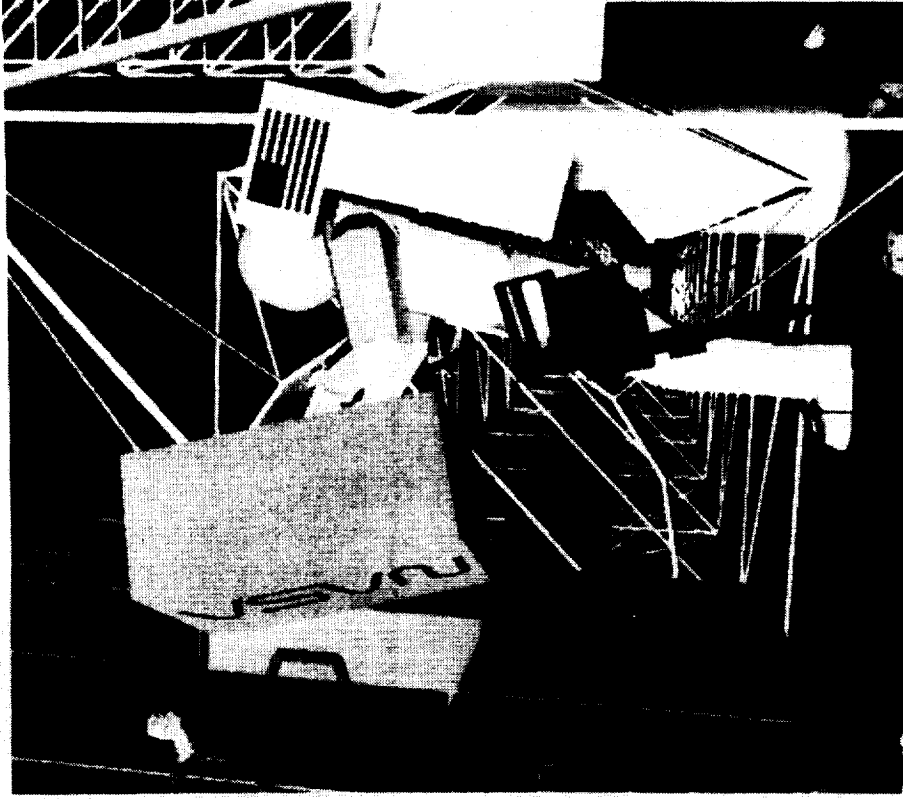
Technical Contact: Barbara Woolford, JSC, (713) 483-3701

Strength and Motion Modeling

- ASSESSING FIT AND REACH THROUGH ANIMATION



LOOSENING THE CONNECTORS



REMOVING THE PAYLOAD

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Strength and Motion Measurement

There exists an operational requirement to develop data on human biomechanical performance in order to plan efficient 0-g and partial-g work protocols. Operationally oriented studies that determine and analyze human strength and motion are conducted for use in man-modeling efforts to support equipment design and operations planning.

Accomplishments in fiscal year 1989 include two major studies and the design of a third. The first study was in support of the Space Station *Freedom* EVA suit design effort. Two prototype suits, JSC's Mark III and ARC's AX-5, were tested for effects on human performance in force production. These tests were carried out in the Weightless Environment Training Facility (WETF—neutral buoyancy facility), and in the 0 g of parabolic flight in the KC-135. Researchers designed tests that employed motions which would be necessary in Space Station activities and that measured the performance of astronauts in each suit. These data are being analyzed as part of the information which will go into the decision regarding which suit to select for use in Space Station *Freedom*.

The second major study analyzed locomotion. Treadmills are used in spaceflight as a method to maintain lower body muscle tone and are being considered as a major health maintenance tool for Space Station *Freedom*. Researchers conducted tests in the Anthropometry and Biomechanics Laboratory and in the KC-135 to determine the biomechanics of treadmill use. Besides tracking the leg motion to determine the pattern of movement, these studies measured EMGs to determine muscle involvement and fatigue. Force sensors were used to measure impact loading on the skeletal system. Part of this study was supported by the Exercise Countermeasure Working Group for Space Station.

A detailed protocol for systematically measuring force production at known joint angles was developed. This will support research at the University of Pennsylvania in developing a strength data base and model for the computerized human modeling. This study will be carried out over the next several months. The strength data base now includes such factors as sex, age, size, and speed of motion as well as joint angles.

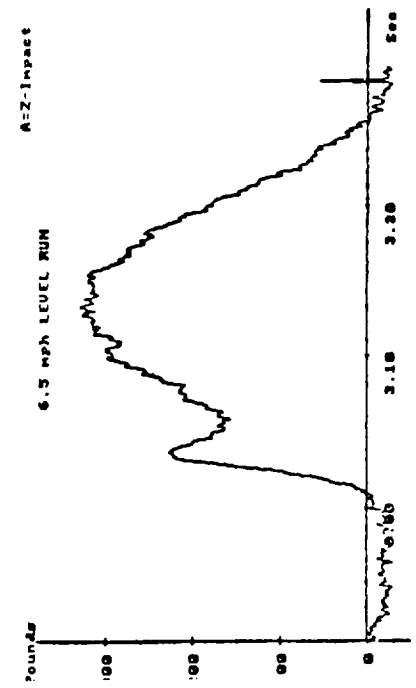
Technical Contact: Michael C. Greenisen, JSC, (713) 483-3874



KC-135 TESTS

LOCOMOTION ON TREADMILL COMPARISON

KINEMATIC ANALYSIS

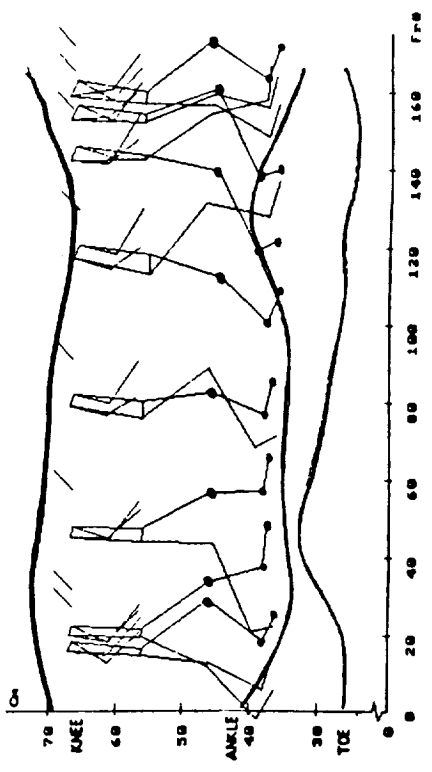


FORCES VS. TIMES

MOTION ANALYSIS

- ZERO-G OR PARTIAL-G MEASURE
- Z-AXIS IMPACT
- LOCOMOTION PATTERNS BY 3-D VIDEO MOTION TRACKING
- EMG OF LOCOMOTION MUSCLES
- ANALYZE FOR
 - ZERO-G AND PARTIAL-G LOCOMOTION PATTERNS
 - IMPACT LOADING OF SKELETAL SYSTEM
 - SKELETAL MUSCLE CONTRACTION PATTERNS

DISPLACEMENT (Z-DIRECTION) OF KNEE, ANKLE, TOE



MOTION MEASUREMENT

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Extravehicular Performance Aids

Extravehicular activity (EVA) is an essential part of human work in space. EVA demands the full attention of the astronaut in monitoring his suit status and performing the task at hand. Information aids can make this monitoring and task performance easier and safer by displaying suit-status data and task checklists in a convenient, easily understandable form. This project has been developing displays of information for EVA through a display to be projected on the helmet faceplate.

Last year's work on the Helmet Mounted Display (HMD) has been continued and extended into a study of information management for EVA. The HMD was interfaced to a MacIntosh computer and used in conjunction with a voice recognition system to conduct an experiment on the accuracy of the voice recognition system. The step-by-step instructions were communicated over the HMD, and navigation through the instructions was by means of voice commands. The results showed that the system had a high success rate in recognizing the command spoken when that command was among the list of allowed commands. However, the experiment disclosed a very significant drawback to voice command; extraneous words were recognized too often as a legitimate command. The parameters of the experiment are being varied and similar experiments conducted to determine whether choosing another word or adjusting the confidence level for recognition can correct this problem.

A major accomplishment this year has been the use of a HMD to determine the utility of displays for the manned maneuvering unit (MMU). The HMD system has been interfaced to the MMU simulation in the Systems Engineering Simulator (SES). Displays for distance to target, amount of fuel, thrusters active, and rotation rates have been developed. These displays are illustrated in the figure. An experiment to assess performance as measured by time to achieve task and amount of fuel consumed is under way. Reports from astronauts, trainers, and engineers have been positive.

Next year's plans include evaluating the HMD-MMU experimental results and considering the HMD as part of the entire EVA information management system, which also contains hard switches, dedicated displays, and spacecraft to EVA astronaut communications links.

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Extravehicular Performance Aids

- DEVELOP INFORMATION MANAGEMENT TECHNIQUES FOR EVA
 - HELMET MOUNTED DISPLAY
 - VOICE COMMAND
 - DATA LINK
- EVALUATE TECHNIQUES
 - VOICE COMMAND TEST
 - MMU SIMULATION

Switches / Pre-EVA / Pg 2 of 7

Automatic Leakcheck

IN PROGRESS

Time left 0:14

- Minimize physical activity
- Breathe normally
- Do not alter O2 actuator or fan

Suit pressure 8.3 psi

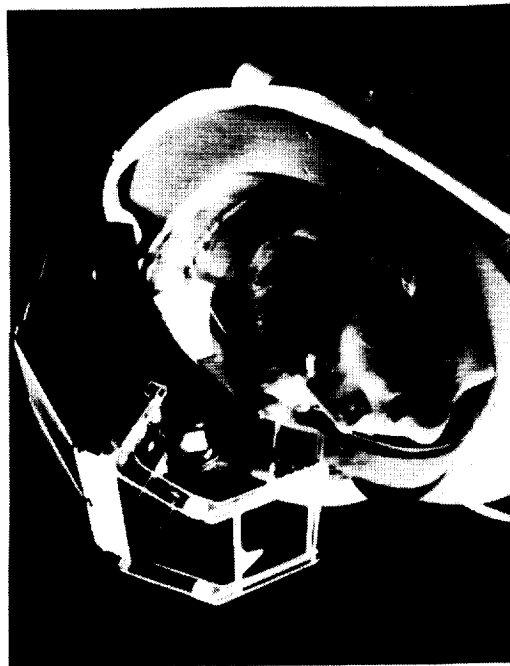
OFF

O2 Actuator has been set to

ACTUATOR		POWER		COMM		IMAGE		TCV	
Off Press EVA		SCU EMU		A HL BU		NR FR		1 2 3 4 5 BRIGHT	
WATER		XHT_PLSS		CAM		LIGHTS SHIELDS		1 2 3 4 5 VOL	
On Off		On Off		On Off		On Off		1 2 3 4 5	

CANCEL to cancel this Leakcheck

EVA PREPARATION



HELMET MOUNTED DISPLAY

A	B
A PROP	B PROP
4K 3K 2K 1K 0	4K 3K 2K 1K 0
2965	2975
MMU INFORMATION DISPLAY	
TARGET & RANGE INFO	
1 2 3 4	
TARGET	SPSTA WSTAR ORBITR
RANGE (ft)	147 213 557
RATE (ft/s)	-1.3 +1.3 -0.7
ATTITUDE HOLD	
ROLL PITCH YAW	
3 9 -2 9 2 9	
61.5 ft/s	
EXIT to display maintenance menu	
ATTITUDE RATE	

DISPLAY FOR MMU

Thermal Control Coatings for Space Suits

The Shuttle EMU and past suit configurations for Apollo and Skylab have used the Integrated Thermal Micrometeoroid Garment (ITMG) to provide thermal protection to EVA astronauts. The ITMG is a multilayer garment that attenuates the incident thermal radiation. It has several inherent characteristics that limit its practicality for a routine Space Station EVA capability, including restricted mobility, complex fabrication, relatively low resistance to atomic oxygen degradation and orbital debris penetration, and a limited lifetime.

The no breathing requirement for Space Station EVA operations has led to the development and evaluation of hard space suits. The hard suit structure affords designers the opportunity to provide passive thermal control to the suit structure. Environmental influence on the suit can be minimized with a high-reflectance coating.

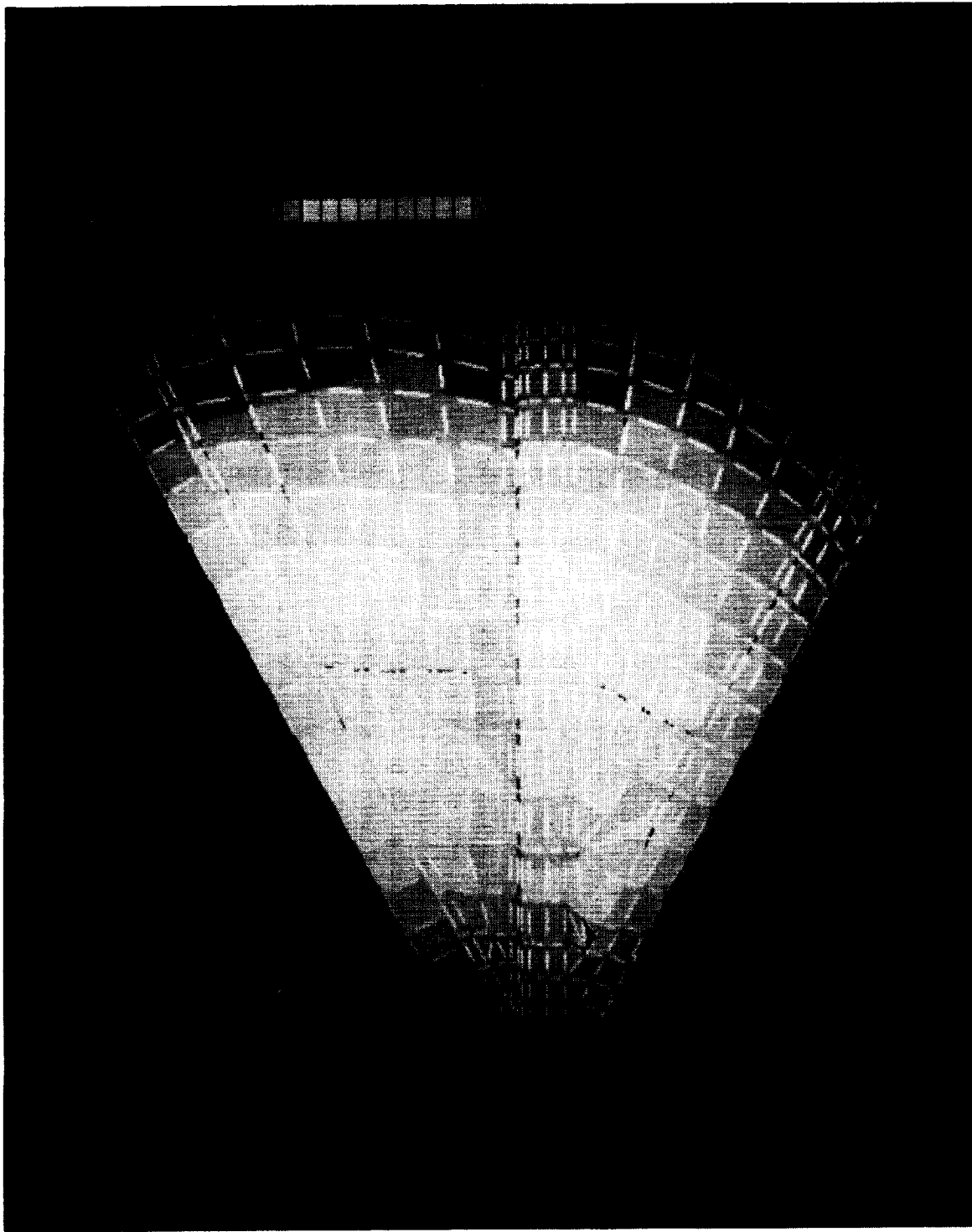
Materials testing on 10 candidate metal coatings has been completed. Both polished and textured substrate surfaces were investigated. Samples have undergone corrosion and abrasion tests with subsequent determination of optical properties to quantify degradation. Additional testing included tape adhesion tests, salt spray fog, and thermal soak.

The plated gold coating on a polished surface exhibited consistently higher reflectance throughout the test protocol. Two suit elements have been plated with gold and will be instrumented for use in a thermal vacuum test. The test article will contain pressurized, temperature controlled, annular gas flow (to simulate ventilation in a suit limb) and will be subjected to simulated components of the Space Station EVA thermal environment.

Data from the test will be used to validate a finite-element computer model of the suit parts in the same environments. Preliminary analyses of the suit elements with a graybody reflectance of 98 percent in a cold environment (radiation to deep space only) yield resultant structural temperatures of 68.3°F. Convective heating in this cold case is 2.25 Btu/hr-ft². Addition of direct incident solar radiation raises equilibrium temperatures to 71°F. Convective cooling is 1.36 Btu/hr-ft². These heating/cooling loads are lower than for past and current suit insulation. The high-reflectance coating isolates the suit from its thermal environment.

The model will be revised to include infrared radiation sources. Infrared radiation will be a significant component of the thermal environment in some Space Station EVA scenarios. After validation of the model with empirical data, several realistic configurations will be analyzed by parametrically varying the model interior convection, suit coating reflectance, and space environment. The model may be adapted for use in research of other thermal environments, such as the Lunar or Martian surfaces.

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Bruce W. Webbon, ARC, (415) 694-6646



Crew Factors in Environments Analogous to Space Operations

In conjunction with the National Oceanic Atmospheric Association (NOAA) and the National Undersea Research Center of Fairleigh Dickinson University in St. Croix, U.S. Virgin Islands, Crew Research and Space Human Factors Branch (FLC) investigators have incorporated the Aquarius undersea habitat as a Space Station *Freedom* analog environment in the FLC research program. The unique undersea setting makes available a natural field situation for systematically observing teamwork and various issues of habitability under relatively isolated and confined conditions.

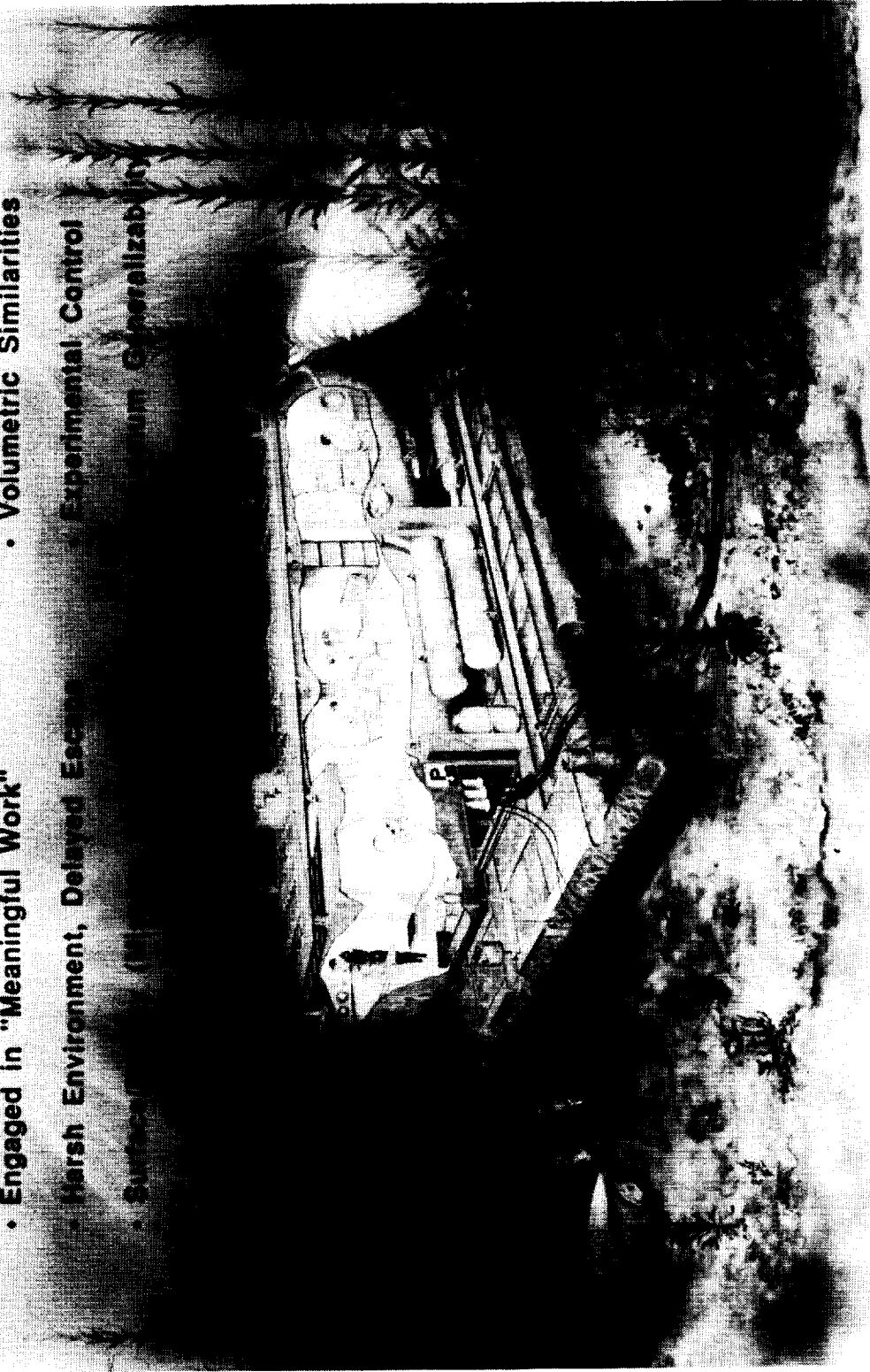
In fiscal year 1988, data collection was completed for 6 teams of oceanographic researchers living and working on the ocean floor for 7 to 14 days in the Aquarius saturated habitat. An additional seven to nine teams will complete dives in fiscal year 1989. Before the dive, each team member completes a battery of measures which includes the personality scales employed in the crew composition simulation and other social/organizational questionnaires. Crew members complete daily and post-dive surveys which, taken with systematic ratings made by topside personnel and the on-site Ames investigator, combine to form an integrated performance measure of task productivity, crew satisfaction, and operational safety. A methodology for making videotaped observations of habitat activities has been developed for focusing on within-habitat team interaction and the interface between habitat and topside teams. Finally, research instruments for investigating habitability issues pertaining to food and sleep have been developed for implementation in fiscal year 1989.

During fiscal year 1988, FLC researchers conducted a preliminary feasibility study of mountaineering environments as a possible analog to crew performance in planetary exploration. Twenty-one teams (110 individuals) participated at Denali National Park in Talkeetna, Alaska (Mt. McKinley) and one team of 12 participated from the Northwest American Everest Expedition in Nepal. Crew members completed personality questionnaires and socio/demographic questionnaires prior to their climb and postassessments of their teams' performance on their return. Results so far indicate that team dynamics are exceptionally tenuous in these high-risk, harsh situations and that group structure (for which there was great variability over only 22 teams) may be highly influential in promoting or breaking down the cohesiveness of the group. There promises to be a potential research interface between crew factors and individual physiological factors that are studied by the ongoing Denali Medical Research Program, as well as an interface between crew factors and the cognitive processing changes in high altitude studied by the University of Washington in cooperation with NASA during the Everest Expedition '88.

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Undersea Scientific Habitat Analogs

- Scientist Inhabitants
- Engaged in "Meaningful Work"
- Harsh Environment, Delayed Escape
- Surface Support (Maintenance, Food, etc.)
- EVA-like Activity
- Volumetric Similarities
- Experimental Control
- Maximum Generalizability



Networks for Image Acquisition, Processing, and Display

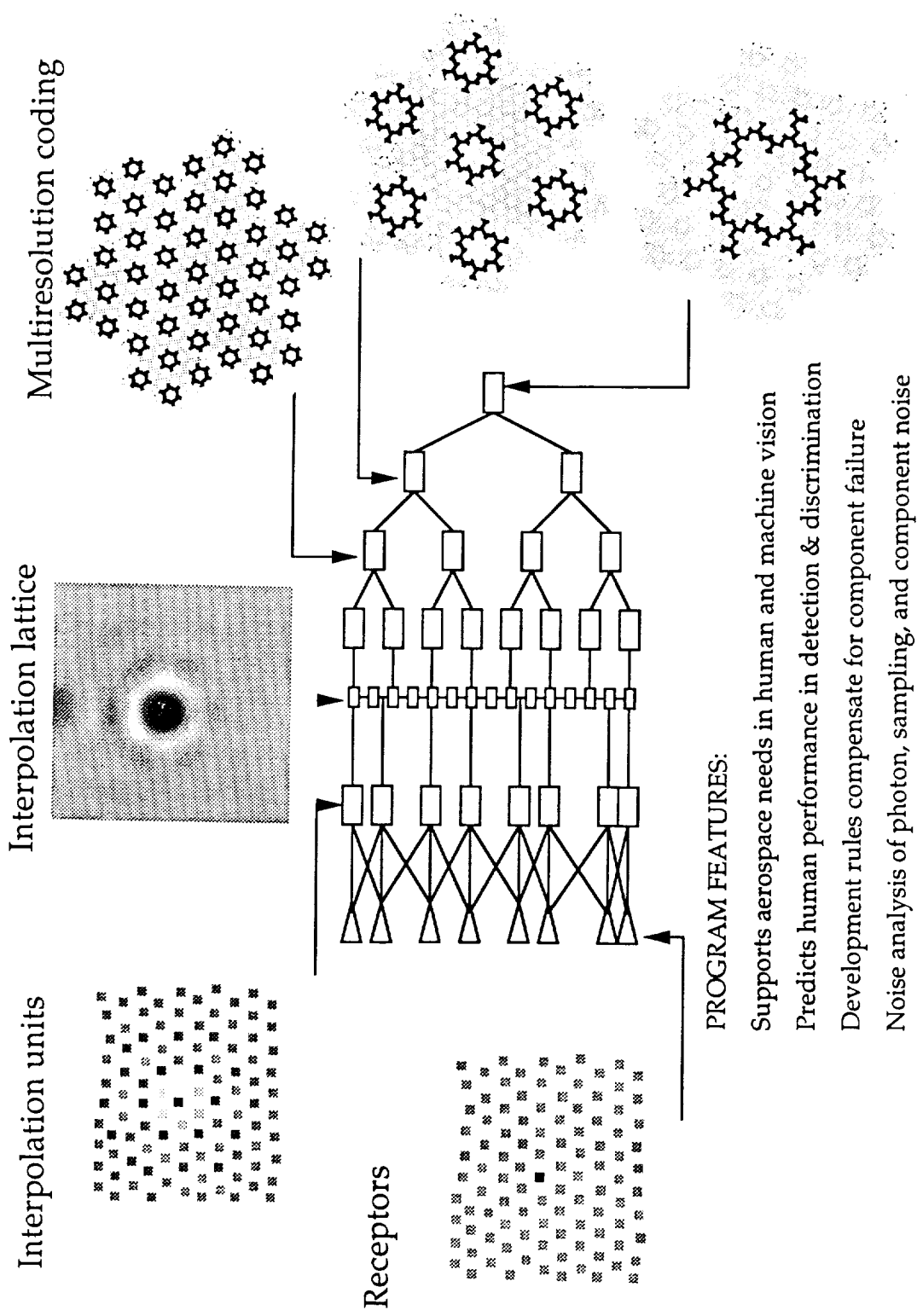
The human visual system consists of networks which sample, process, and code images. Understanding these networks is a valuable means of understanding human vision and of designing autonomous vision systems based on network processing. The Human Interface Research Branch (Code FLM) has an ongoing program to develop computational models of such networks.

The models predict human performance in detection of targets and in discrimination of displayed information. In addition, the models are artificial vision systems sharing properties with biological vision that has been tuned by evolution for high performance in complex, dynamic environments. Properties include variable density sampling, noise suppression, multiresolution coding, and fault tolerance. The research stresses analysis of noise in visual networks, including sampling, photon, and processing unit noises.

Specific accomplishments include models of sampling array growth with variable density and irregularity comparable to that of the retinal cone mosaic, noise models of networks with signal-dependent and independent noise, models of network connection development for preserving spatial registration and interpolation, multiresolution encoding models based on hexagonal arrays (HOP transform), and mathematical procedures for simplifying analysis of larger networks.

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Andrew B. Watson, ARC, (415) 694-5419

Networks for Image Acquisition, Preprocessing, and Coding



Computational Models of Attention and Cognition

Human operators are limited in their ability to process and respond to multiple information sources. Aviation and space environments impose severe visual, auditory, and decision-making demands in situations where human failure can have catastrophic results. Information overload has been identified as a major contributor to error in military aviation—especially helicopter Nap-of-the-Earth (NOE) operations—and in critical monitoring tasks such as air traffic control and ground control of space missions.

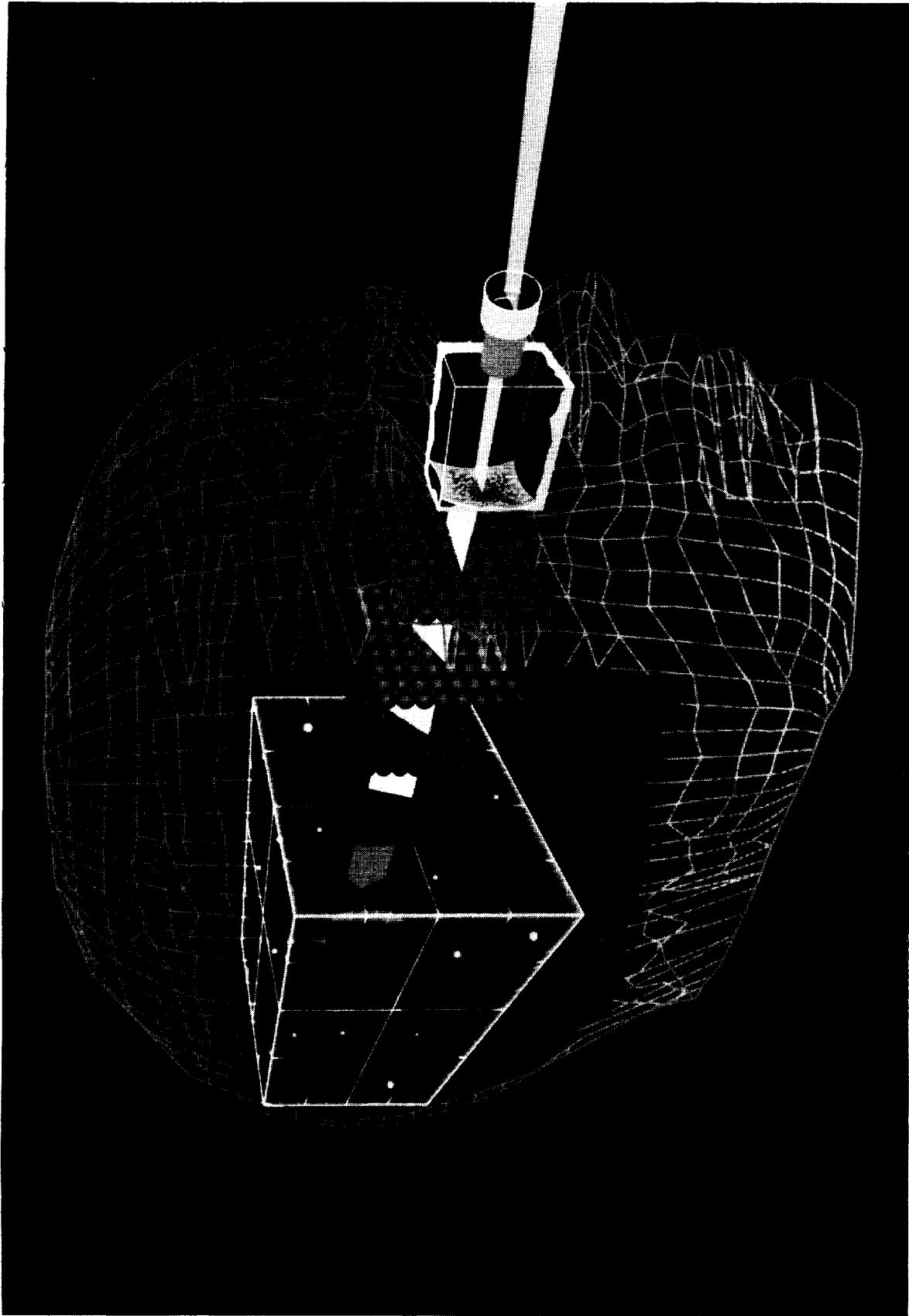
The ultimate solution to problems arising from limitations on attention and cognitive capacities will come from optimal allocation of function between human and machine combined with optimal configuration of multimodal displays and controls. The realization of such optimization depends on a deeper understanding of attentional control. This can be achieved by developing validated computational models of human information processing.

The Human Interface Research Branch (Code FLM) has an ongoing research program in attention and cognition focused on determining the mental resources underlying complex task performance. This research has identified stimuli that control attention and situations where distraction will be unavoidable, making it possible to design displays that better capture and direct an operator's attention. Work on cognitive architectures has led to models of simple multitask settings that will aid decisions about the use of speech controls and displays, and about the allocation of tasks between the human operator and automated subsystems. Current research will extend these findings to more complex task environments by developing methods for mapping complex tasks onto underlying mental resources, conceptualizing, implementing, and iteratively refining computational models of human cognition, and developing mathematical models of the allocation, control, and mechanisms of human attention and performance.

Several aerospace scenarios are being investigated as a basis for analysis and model development. These include ground control of manned and unmanned space operations, helicopter NOE and search-and-rescue operations, and air traffic control and Space Station *Freedom* proximity operations.

The research program involves extensive in-house research and model development while supporting related modeling efforts at universities. Related efforts within the Aerospace Human Factors Research Division (Code FL) address interface design and evaluation, work load, methods of assuring proper levels of alertness in civil air transport, and pilot error.

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Sensor Systems

The objective of the Sensor Technology Program is to provide necessary expertise and technology to advance space remote sensing of terrestrial, planetary, and galactic phenomena through the use of electromagnetic and electro-optic properties of gas, liquid, and solid-state materials technology.

The Sensor Technology Program is divided into two subprograms: a base research and development program and a Civil Space Technology Initiative (CSTI) program. The base research and development consists of research on artificially grown materials such as quantum well and superlattice structures with the potential for new and efficient means for detecting electromagnetic phenomena. Research is also being done on unique materials and concepts for detector components and devices for measuring high-energy phenomena such as UV, x-, and gamma rays that are required observables in astrophysical and solar physics missions. The CSTI program is more mission driven and is balanced among four major research and development disciplines: (1) detector sensors; (2) submillimeter wave sensors; (3) LIDAR/DIAL sensors; and (4) cooler technology. The first discipline plans to develop large spatial-imaging format arrays in the near (1 mm-30 mm wavelength) and far (30 mm-200 mm wavelength) infrared portions of the electromagnetic (EM) spectrum. These goals are crucial to enable spaceborne remote sensing for the various terrestrial, planetary, and astrophysical missions. The submillimeter discipline is dedicated to developing the technology to enable heterodyne receiver instruments for remote sensing in the 300 GHz to 3000 GHz frequency regions of the EM spectrum with a focus on developing local oscillators, frequency mixers, and quasi-optical technology in this region. Backward wave oscillators, lasers, and quantum well devices may also have potential as oscillators. In the third area, the acronym DIAL/LIDAR (DIAL means Differential Absorption LIDAR and LIDAR means Light Detection and Ranging) consists of research on techniques for enabling active remote sensing in which a coherent source such as a laser is used to probe the environment. Research is concentrated on technology for obtaining tunable, frequency stable, and pure space qualifiable lasers. Finally, in the last discipline, research is in progress on technology to enable cryogenic coolers in the Kelvin to sub-Kelvin temperature regions in support of the efforts in the detector and submillimeter wave sensor thrusts. Work includes research on various cooler concepts such as the pulse tube, adiabatic, Helium 3, and zero-gravity refrigerators and their corresponding component development.

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Ti:Sapphire Technology Proposed for Eos

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The challenge of this technology is that Ti:Al₂O₃ is an efficient, high-gain, tunable laser source that spans the spectral region from $<0.7\text{ }\mu\text{m}$ to $>1.0\text{ }\mu\text{m}$. Unlike Cr:BeAl₂O₄, Ti:Al₂O₃ has a large effective stimulated emission cross section; consequently, it can operate efficiently and reliably at low pumping energy densities. With the advent of laser-diode-pumped Nd-based lasers, this material can be laser pumped efficiently and reliably. Projected system efficiencies are in excess of 5 percent.

The significance is that Ti:Al₂O₃ provides the needed tunable laser source in the $0.7\text{-}\mu\text{m}$ to $1.0\text{-}\mu\text{m}$ region for lidar and DIAL (Differential Absorption Lidar) experiments. A Ti:Al₂O₃ laser accesses both weak water vapor absorption bands at approximately $0.73\text{ }\mu\text{m}$ and the stronger water vapor bands at approximately $0.94\text{ }\mu\text{m}$, allowing accurate measurements for a wide dynamic range of water vapor concentrations. Oxygen bands at approximately $0.76\text{ }\mu\text{m}$ are accessed by Ti:Al₂O₃. Thus, a single lidar instrument can perform three important DIAL experiments.

This technology has several impacts. Water vapor and pressure/temperature measurements continue to surface as prime scientific parameters in the atmospheric sciences and meteorological community. Knowledge of global water vapor distributions is required for studying climate, the hydrological cycle, and meteorological processes. Temperature distributions will provide invaluable science on tropopause heights and meteorological conditions. Such a source also makes a valuable research tool in the spectral region in which tunable dye laser performance is limited.

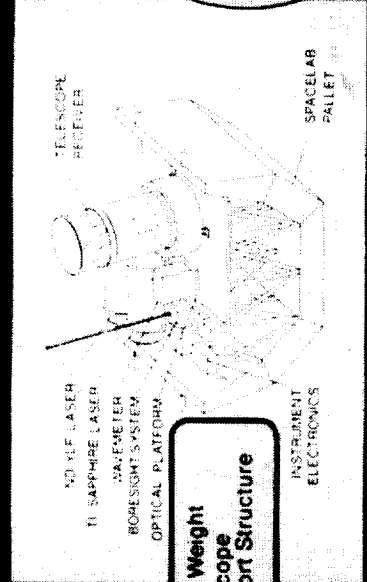
Accomplishments include a Ti:Al₂O₃ laser that produces an 0.24 J/pulse ; this has been demonstrated under a LaRC-funded contract. When operating with a narrow spectral bandwidth ($\leq 1\text{ pm}$) using injection locking, 0.18 J was produced. By using injection-locking technology, a single-frequency power oscillator can be achieved. Such a design reduces the number of amplification stages and delivers the spacecraft design for optimizing efficiency, weight, and reliability. Two injection sources have been developed under a LaRC contract. Both sources depend upon a single-mode Ti:Al₂O₃ laser oscillator. One source is a continuous wave device and the other is a quasicontinuous wave device. The threshold of the continuous wave device is 0.35 W , making it significant for a laser-diode-pumped, frequency-doubled Nd:YAG laser as the pump. Similar devices can be used as wavelength standards for all three wavelengths of interest.

Amplified spontaneous emission (ASE) has been demonstrated to be a solved problem for Ti:Al₂O₃. In a complex experiment, using an Rb absorption cell to selectively absorb the ASE laser output, the ASE of a Ti:Al₂O₃ laser amplifier was measured to be <0.1 percent. According to Frank Allario of LaRC, this major accomplishment was the last in a series of strategic research goals established by LaRC's research program in 1983. LaRC considers technological demonstrations for Ti:Al₂O₃ to be completed. The challenge for the future is to demonstrate a "full-up" functional demonstrator and to convince scientific and technological personnel that this infant technology is a scientific reality.

Technical Contact: Norman Barnes, LaRC, (804) 864-1630

TALOS: LITE & Ti:Sapphire

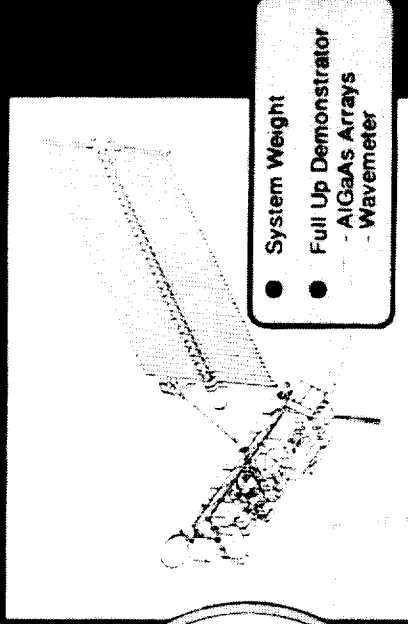
Eagle: All solid state & Ti:Sapphire



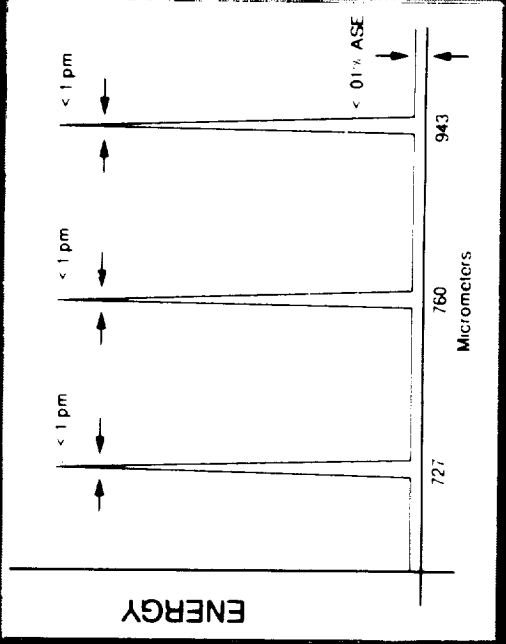
- System Weight
- Telescope
- Support Structure

Industry

4 Commercial Products Announced CLEO '89



Recent Accomplishments Demonstrated



Future:

- Accelerate CSTI Goals from
 - Current: 250 mj/pulse
 - To: 1000 mj/pulse
- Full up Performance:
 - LASA Brassboard
 - Flight Prototype

Far-Infrared Optical Component Development

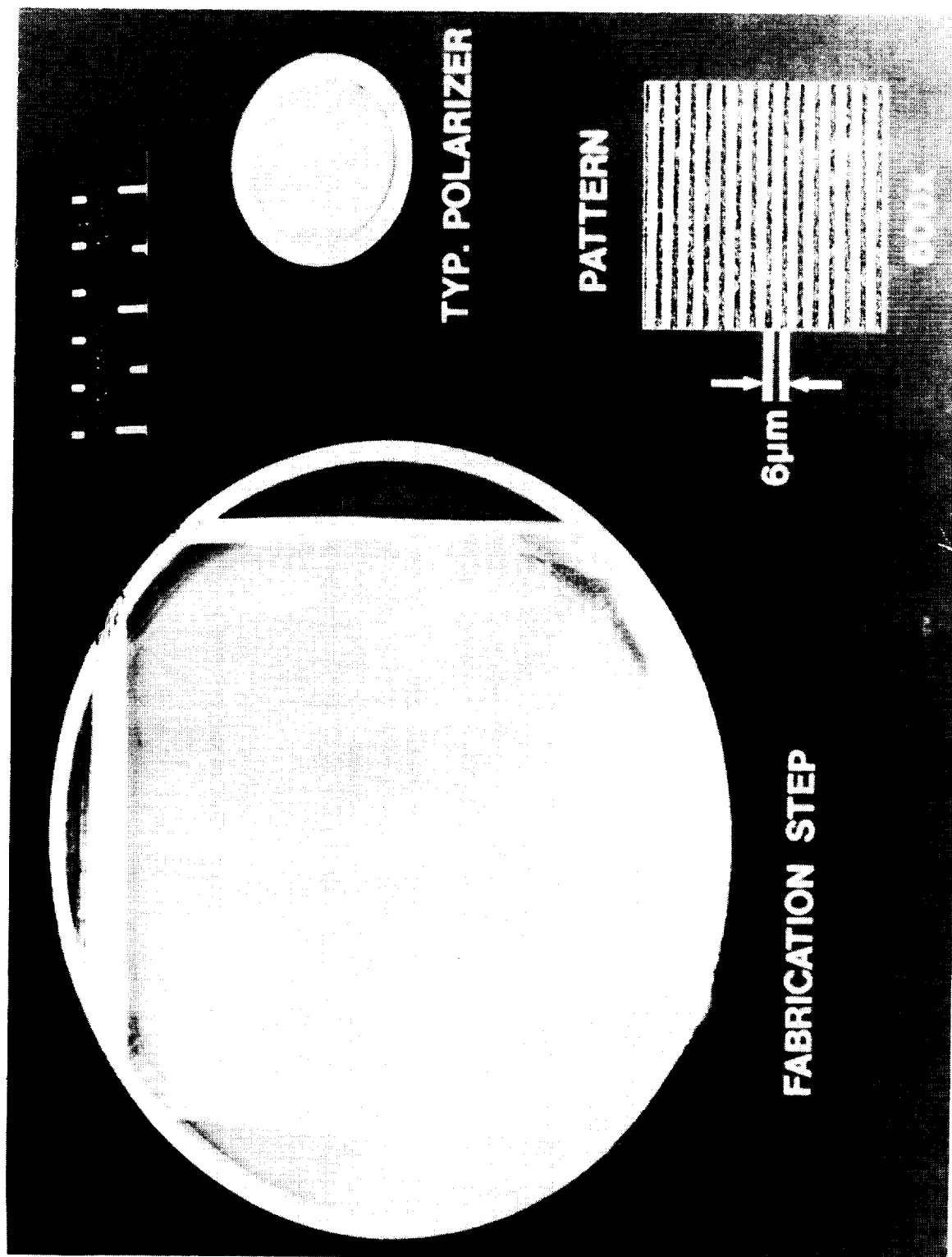
The objective of this program is to develop or improve the basic technology of optical components that are needed for Earth sensing in the far-infrared spectral range. The focus of the present work is to improve photolithographic metal mesh-based devices for polarizers, dichroics, and narrowband filters.

The central problem in applying far-infrared sensors to Earth observation is the discrimination of generally weak signals in the presence of high-thermal infrared backgrounds. Needed are the full range of narrowband filters and other optical components. Metal mesh etalons on ultra-thin dielectric membranes provide a promising solution provided that reliable, accurate, and reproducible photolithographic technology can be perfected.

LaRC has a modern, well-equipped photolithographic facility in the Microelectronics Laboratory, which supports thin-film-device fabrication of aeronautical model research. This expertise has been used to produce prototype devices in copper film deposited on thin dielectric membranes. As the first objective, large-diameter polarizers have been successfully fabricated which meet the requirement of potential satellite and balloon instruments for diameters as large as 25 cm. This size is approximately 10 times larger than those that are commercially available. Polarizer tests and devices have been shared with GSF, and commercial interest also has been expressed. A planned technical publication will enable commercial utilization of this technology.

Current effort is now directed toward the improvement of metal mesh photolithography for etalons essential to the construction of very narrowband filters. Such filters are needed in all Earth-sensing infrared experiments in order to reduce the background photon noise. The key problem here is very accurate replication in copper film, along with the development of proven engineering design models. Present techniques can provide filters that have a passband of approximately 4 wavenumbers at 100 wavenumbers, or an effective Q of 25. The objective of present development is to improve filter Q by a factor of 4 in the next 2 years, along with achieving more reliable and predictable design models.

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New Research Tools Developed to Focus Rare Earth Materials Technology for Wind Shear Lidar

New research tools have been developed to advance the technology of mid-IR (infrared) lasers. These new tools include spectroscopic measurements and the computer techniques for analysis, a unique variable temperature, flashlamp-pumped laser system, and laser models to guide analysis of empirical data. The ultimate goal is to guide engineering performance.

Mid-IR lasers are significantly more complex than Nd-based lasers, thus requiring a coordinated, sophisticated approach to optimizing laser systems. Complexities include the use of Co-doped sensitizers and non-negligible lower laser level population density. To optimize such a system, the laser material, the concentrations of both the active atom and sensitizer, and the operating temperature must all be considered. The national solid-state laser community is currently in a scientific race to optimize these complex materials for a variety of applications. At LaRC two specific applications are contemplated; these applications include lidar wind shear avoidance techniques (at 2.09 μm) and DIAL measurements of the carbon monoxide molecule (at 4.7 μm). LaRC has launched a unique program in materials development, mathematical modeling, spectroscopy, and data base development to bring this exploding technology to early fruition.

The Ho, Er, and Tm lasers have the potential to serve as efficient, laser-diode-pumped sources in the eyesafe region of the spectrum. Such devices could be used directly to perform wind shear measurements. Their ability to provide continuous-wave and pulsed-laser sources, coupled to a higher backscatter coefficient, makes them nearly ideal candidates for this role. They also serve as sources for lidar instruments by coupling them to nonlinear wavelength conversion techniques.

A crystal field model for Lanthanide series laser materials has been obtained from the Harry Diamond Laboratories and is currently operating at LaRC. This has significantly increased the capability of our data base development program. Software has been written to analyze elusive energy transfer rates, between sensitizer and active atoms. The combination of energy levels and empirical emission and absorption spectra will provide the key to Q-switching these materials efficiently. A Dexter integral approach is used for the latter calculations.

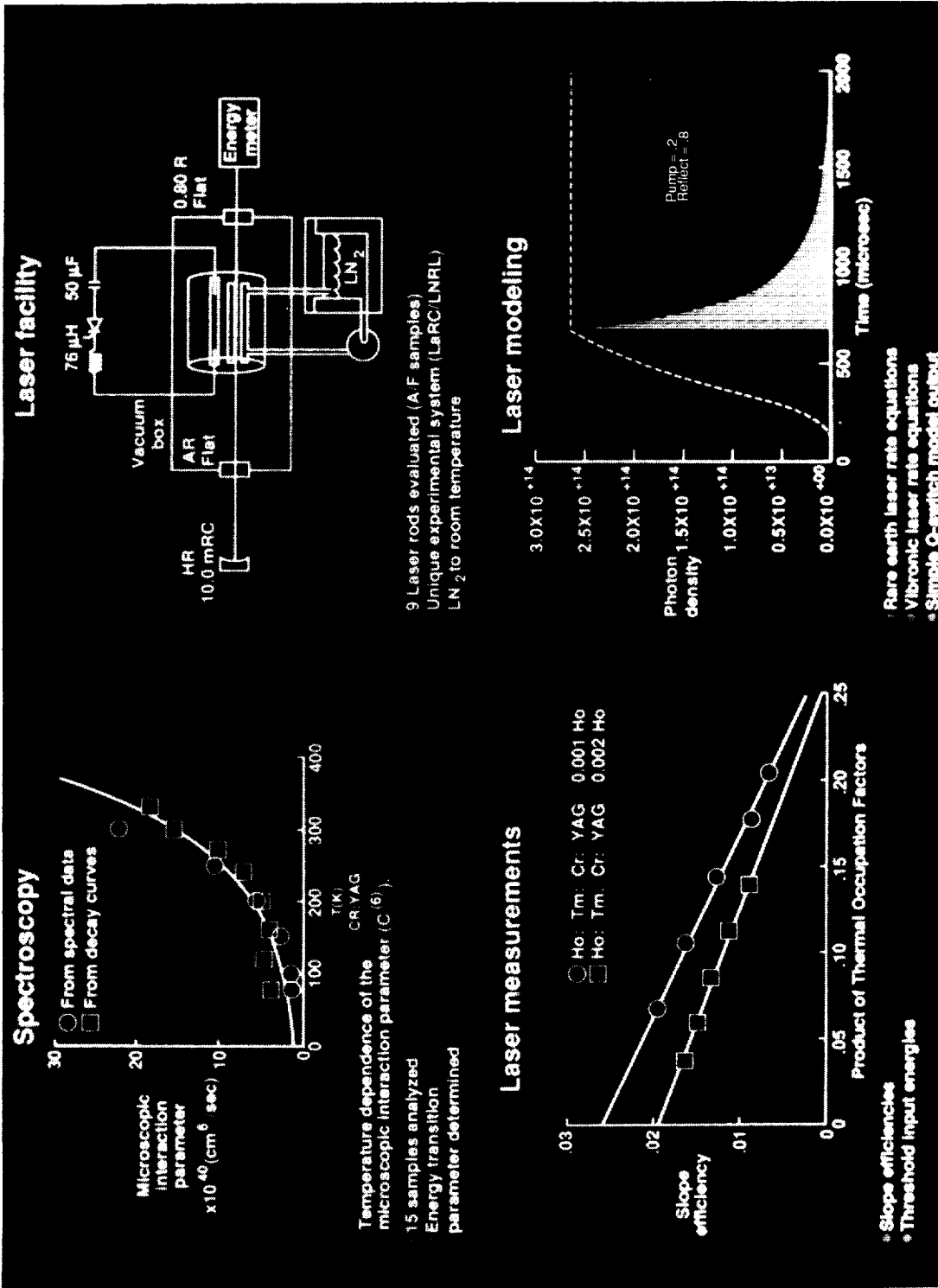
Energy transfer rates of Ho, Tm, and Er in YAG and YLF have been measured as a function of temperature. Measurements have been made both using the Dexter integral overlap method and by directly measuring the rise and decay of fluorescence.

Laser performance data have been assimilated for two compositions of Ho:Tm:Cr:YAG and for one composition of Ho:Tm:Er:YAG as a function of temperature and output mirror reflectivity. Laser performance data were analyzed to obtain maximum slope efficiency and minimum threshold data as a function of temperature. Excellent correlation was found between these data and the model having parameters that depend directly on function of thermal occupation factors.

A two-dimensional laser oscillator model has been developed. Time and longitudinal position are the two variables. Relaxation oscillation effects have been predicted by the model.

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New Research Tools Developed to Focus Rare Earth Materials Technology for Wind Shear Lidar



Progress in Semiconductor Laser Arrays for Pump Sources

The McDonnell Douglas Corporation development program for a 1-J all-solid-state laser at 1.06 μm with doubling to 0.532 μm is on schedule with a preliminary demonstration slated for the late July to early August 1989 time frame. Earlier diode array production problems apparently have been corrected so that there will be little impact on the schedule for the final laser system delivery.

FIBER-TEK's original contract for producing a 1.06- μm diode-pumped laser with an output of 0.5 J has received additional funding and scaled to 1 J. They are also on schedule for a preliminary demonstration at the 0.5 J level, by late July or early August 1989.

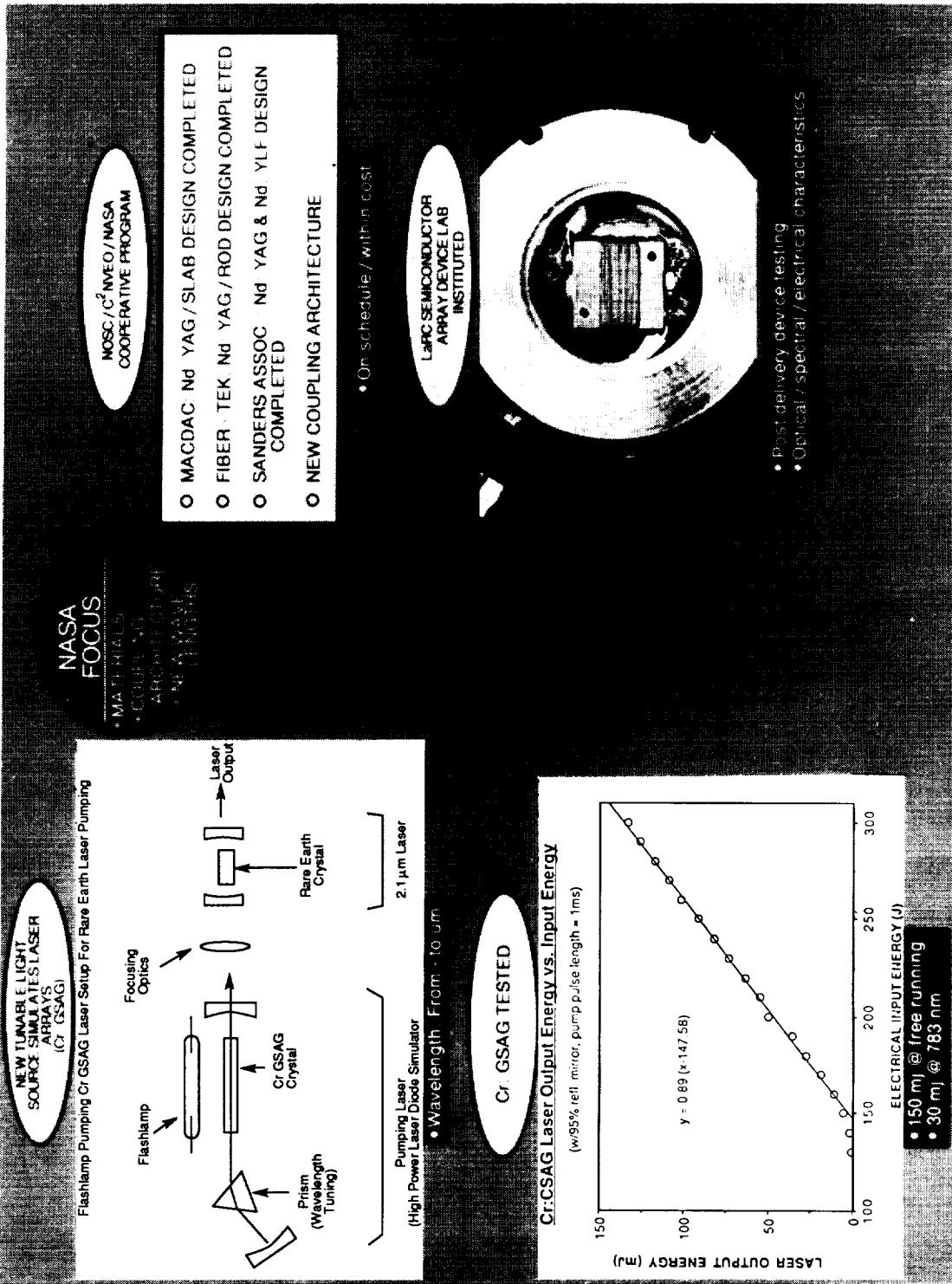
The Sanders Associates contract to compare the performance of diode-pumped Nd:YLF versus Nd:YAG is encountering a delay due to problems in delivery of semiconductor laser pump arrays. They are continuing on schedule with development of the Compound Parabolic Concentrator (CPC) element, a unique architecture to pump radiation into the solid-state laser media. The CPC is composed of two opposing parabolic reflecting surfaces that funnel radiation from the source to the laser media, producing uniform illumination of the media and slight collimation of the pump beam. They are also expected to conduct a preliminary demonstration of their efforts in the late July to early August 1989 time frame.

The Diode Laser Test Facility can measure either pulsed or continuous (CW) device characteristics. This facility has in place data acquisition capability to record information and assist in establishing a diode laser data base. The main parameters of interest are radiant power output versus device drive current, device current versus voltage (e.g., electrical input power), spectral distribution, and device lasing threshold current versus temperature. Additional parameters of interest are the initial chirp of the wavelength after onset of the current drive pulse and the slower drift of wavelength after operational temperature has been reached. Near-field intensity distribution is also important. All of these parameters can be and are measured in this facility. Recently, the facility acquired an 80-channel custom diode laser reliability test system from the United States Air Force. During fiscal year 1989, this system will be brought on-line to perform life test measurements on arrays and other diode lasers. This will expand the facility's evaluation capabilities.

Due to the relatively high costs of semiconductor laser arrays and the long lead delivery times required from the primary commercial source, it was decided to develop a solid-state laser source to simulate optical pumping of laser materials. In particular, the interest was to evaluate improvements in efficiency under various pumping architectures and to evaluate pumping efficiencies at wavelengths other than the conventional band gap and wavelengths for AlGaAs at 810 nm. A Cr:GSAG solid-state laser source was developed to simulate laser radiation from semiconductor laser arrays. The laser radiation is tunable from 0.70 nm to 0.85 nm. One hundred fifty mJ/pulse of free-running laser radiation has been achieved, and 30 mJ/pulse at 783 nm has been demonstrated. This laser will be used to simulate semiconductor laser array pumping at several new wavelengths, and focusing optics will be incorporated to simulate the divergence properties of laser array architectures.

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Progress in Semiconductor Laser Arrays to Optically Pump Solid-State Laser Materials



Progress in Mid-Infrared, Frequency Agile Solid-State Lasers

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Coverage of the spectral region from 2.5 μm to 12.0 μm can be obtained by utilizing nonlinear wavelength conversion techniques with the eyesafe Ho, Tm, and Er lasers. Optical parametric oscillators and amplifiers are being investigated using an Er:YLF pump laser and AgGaSe as the nonlinear material.

A tunable laser source in the mid-infrared region of the spectrum is needed for remote sensing of the atmosphere. Weak overtone bands in the near-infrared region can be used for atmospheric constituents that are abundant, such as water vapor and oxygen. Trace gasses, such as carbon monoxide, ozone, and methane, require lidar systems that will interrogate the stronger fundamental absorption bands in the mid-infrared. Nonlinear wavelength conversion techniques can be utilized to transform the Ho, Tm, and Er lasers into tunable sources to cover this wavelength region.

Global atmospheric monitoring of the greenhouse effect and the ozone hole will require three-dimensional measurements of the distribution of trace gasses, such as carbon monoxide, ozone, and methane. Lidar systems from space are one of the few methods for obtaining these data. Nonlinear wavelength conversion techniques will allow lidar systems to be developed which will measure all these atmospheric constituents. When coupled with laser-diode-pumped Ho or Tm lasers, efficient and compact laser systems are enabled.

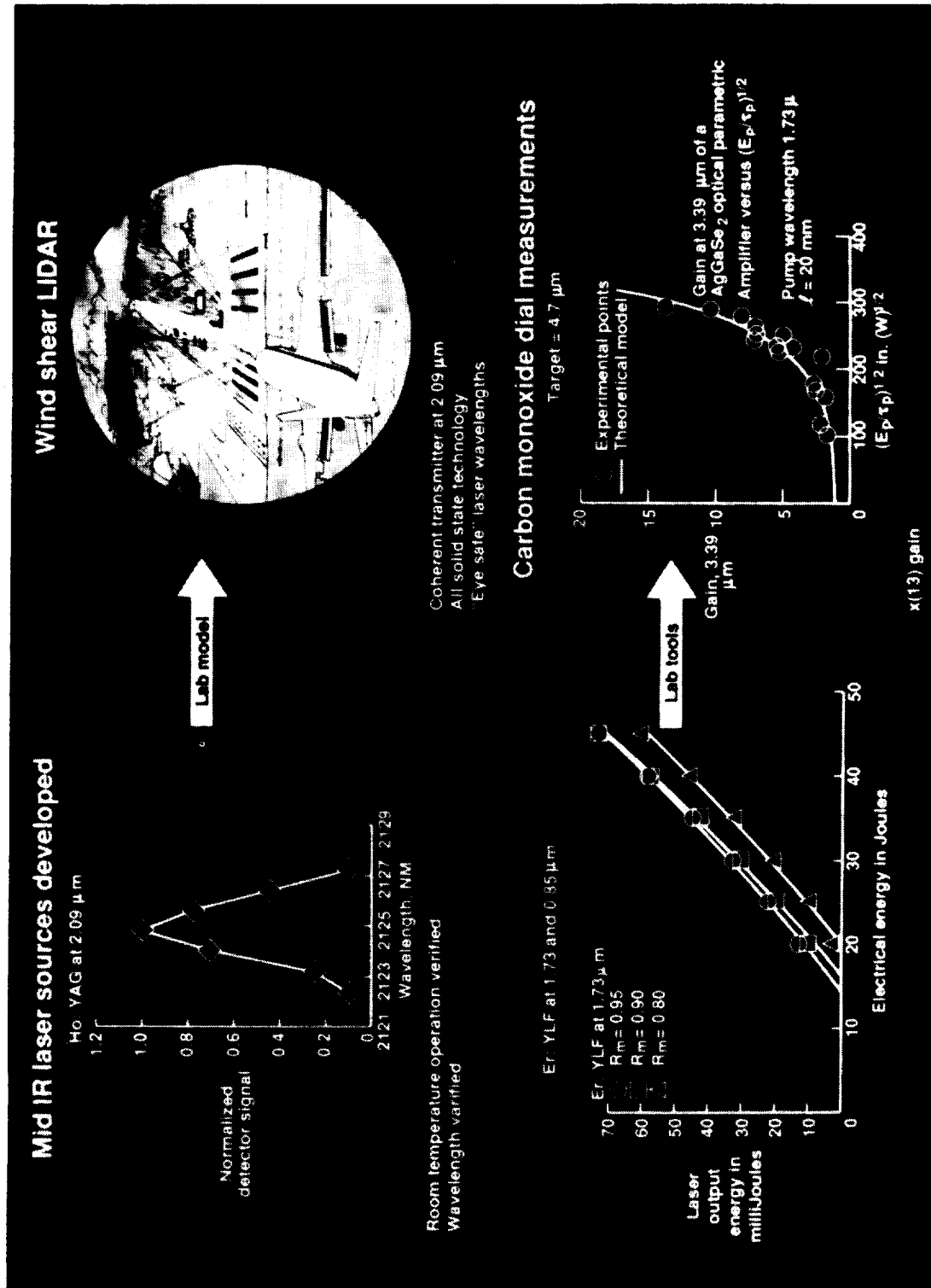
The accomplishments of this research include a continuous wave laser-diode-pumped, room temperature Ho:YAG laser that has been demonstrated at LaRC. Tuning results indicate that the nominal operating wavelength, approximately 2.12 μm , can be tuned to coincide with atmospheric transmission peaks.

A room temperature Er:YLF laser, operating at 1.73 μm , has been fabricated and characterized for both normal mode and Q-switched operation. The Er:YLF, presently confined to operating in the TEM₀₀ mode, makes an effective pump laser for nonlinear optical experiments. Self-cascade lasing on this transition was investigated and found not to be an observable effect.

AgGaSe has demonstrated a single-pass optical parametric amplification in excess of 13. The optical parametric amplification was compared with a model that takes into account the nonuniform gain associated with a TEM₀₀ pump beam profile. The agreement between the model and experimental data was good. The crystal length for these experiments was only 22 mm. As longer crystals become available, even higher gains may be expected. Homogeneity of the nonlinear crystal was evaluated by measuring the tuning curve and comparing it with the theoretical tuning curve. A good agreement was found between the two tuning curves.

ZnGeP₂ is the next nonlinear crystal that will be investigated as part of the program. Until now, the material was only available from Soviet bloc countries. Under United States Air Force sponsorship, three United States companies are aggressively developing this material. Under a joint LaRC/Air Force Memorandum of Agreement (MOA), LaRC plans to procure a nonlinear crystal and conduct testing and characterization with the new laser pump sources.

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Additions to Data Base for Solid-State Laser Materials and Design

A laser data base and modeling capability has been established to allow pertinent data on laser materials to be stored. A set of laser models, which draws from the data base, has been established to analyze laser performance. Data base entries include laser material parameters, such as energy levels and absorption spectra, and optical information, such as refractive index and thermo-mechanical properties. Models include both macroscopic parameters, such as partition functions, to evaluate thermal occupation factors, and other models, such as laser amplifier models.

While data describing laser and optical materials are available in the literature, they are not in a form lending to facilitate use. Some of the data, such as absorption spectra, are simply too detailed to be easily presented in the literature. A data base was initiated to gather all necessary basic data into one computer file, with user-friendly access. In addition, laser models that will utilize the data have been incorporated into the data base. When complete, a laser engineer will be able to analyze a laser by using the laser models and physical parameters in the data base as an engineering tool.

Many possible laser materials and designs need to be investigated. An empirical approach to laser design is totally impractical. By establishing the data base and associated laser models to utilize the data, potential laser performance can be predicted. Once established, this combination will allow the laser engineer to assess the efficacy of laser design changes. Thus, only the most promising design changes can be implemented and tested for the predicted increase in laser performance. By eliminating poor design, the efficiency with which the laser designer operates should be greatly enhanced.

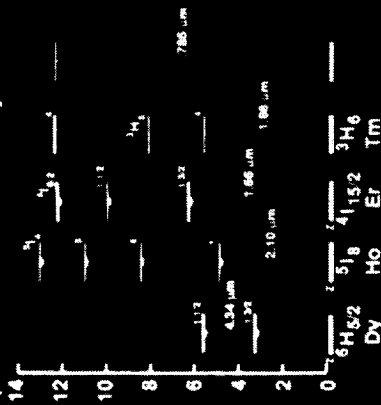
Two energy transfer models have been written. One model estimates the energy transfer rate between two atoms using only the position of the energy levels. A second program accurately calculates the energy transfer rate based on a Dexter integral formation. In addition, an absorption efficiency program has been written which not only calculates the absorption efficiency but also calculates the radial distribution of stored energy for azimuthally symmetric laser geometries.

Sellheir coefficients for 21 optical materials have been added to the data base. In many instances, the Sellheir coefficients had to be obtained by curve fitting the index of refraction versus the wavelength data. Nonlinear coefficients for 150 nonlinear optical materials have been added to the data base. A program to calculate the effective nonlinear coefficient for uniaxial crystals has been implemented. A laser amplifier model has also been added to the existing set of laser models. Both loss at the laser wavelength and nonuniform energy storage have been taken into account. The amplifier model was verified by comparison with experiment.

To date, the data base has been utilized to identify optimum material properties of solid-state lasers and nonlinear materials, as independent units. An effort is currently ongoing to develop this model for engineering models of laser transmitters, capitalizing upon LITE (Lidar in Space Technology Experiment) and LASE (Lidar Atmospheric Sensing Experiment) engineering models.

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Physics model of La-elements in crystalline materials (transferred from Harry Diamond Labs)



4-computer programs
Operational procedures established
Dexter integrals = transfer rates

Optical Parametric Oscillator (OPO)

- Sellher coefficients (21 materials)
- Non linear coefficients (150 materials)
- 2 candidates for OPO:
Ag Ga Se₂ (x 13 reputed, 1988)
Zu Ge Pz (new material)

NASA AF joint program

Spectroscopic parameters Nd: Based lasers (analysis)

Material	λ_L	λ_E	λ_2	λ_{PM}	$V(0.9)$
Nd: YAG	1.064	3.4	244	.8075	.0040
Nd: YLF			480		
σ	1.053	2.6		.8000	.0035
π	1.047	3.7		.7825	.0060
Nd: GSGG	1.061	1.1	222	.8065	.0045
Nd: BEL			142		
X	1.070	2.1		.8110	.0040
Y	1.078	1.5		.8110	.0055
Z	1.079	0.6		.8105	.0055
Nd: YVO ₄			98		
σ				.8000	.0045
π	1.064	6.2		.8065	.0060
Q-98	1.053	0.45	308	.8075	.0060

Selected for DOD/NASA studies

Spectroscopic parameters Nd: Based (LaRC generated)

Material	λ_A	λ_S	λ_P	P
Nd: YAG	.64	.75	.73	.35
Nd: YLF σ	.40	.86	.69	.24
Nd: YLF π	.64	.86	.73	.40
Nd: GSGG	.57	.73	.51	.21
Nd: BEL X	.72	.62	.66	.30
Nd: BEL Y	.72	.62	.59	.26
Nd: BEL Z	.72	.62	.35	.15
Nd: YVO ₄ σ	.75	.51	.75	.28
Nd: YVO ₄ π	.65	.51		
Q-98	.56	.79	.28	.12

Emission & absorption spectra
19 YAG samples
200 raw data files

ORIGINAL PAGE IS
OF POOR QUALITY

New Tunable Infrared Laser for Commercial Market

SBIR Co:MgF₂

Co:MgF₂ is a solid-state laser that tunes from approximately 1.7 μm to 2.4 μm . Although discovered in 1964, it did not become a practical device until the advent of laser pumping techniques. These techniques enabled the low effective stimulated emission cross section to be compensated to a degree by the high inversion density. Thus, reasonable gains and concomitantly reasonable efficiencies can be obtained. A second major advancement is the demonstration of efficient room temperature operation. Previously, Co:MgF₂ had been operated at cryogenic temperatures (77 K) to achieve efficient operation. By utilizing cryogenic cooling, the upper laser level lifetime is sufficiently long so that the threshold could be achieved at reasonable pump power densities. Through a LaRC-funded SBIR (Small Business Innovative Research) grant, efficient room temperature operation was demonstrated by utilizing short pump pulses.

Co:MgF₂ provides a tunable laser source in the 1.7 μm to 2.4 μm region for both lidar/DIAL and spectroscopic research. From a lidar viewpoint, the 1.7 μm to 2.4 μm region is highly interesting due to the presence of carbon monoxide, methane, and carbon dioxide overtone bands. All of these gases are of interest because they contribute to the greenhouse effect. Spectroscopically, such a source is invaluable because it provides a high-intensity short-duration pulse for excitation in a spectral region in which no tunable source exists. Such a source is invaluable for the study of energy transfer dynamics.

The use of the Co:MgF₂ laser will allow demonstration of lidar to detect carbon monoxide and other trace gasses. In addition, such a demonstration will provide direct determination of the requisite performance parameters of such a lidar. Spectroscopically, such a laser will provide an invaluable tool for the investigation of energy transfer rates in other Lanthanide series laser materials. Such a source is especially critical as the upper laser level of Ho, Er, and Tm all lie in this spectral region.

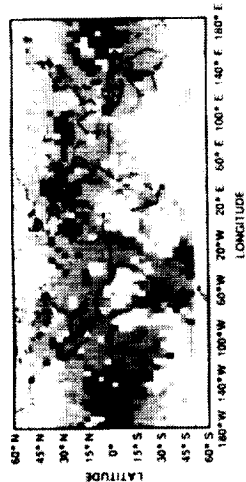
The performance of Co:MgF₂ was characterized as a function of temperature. While performance at cryogenic temperatures had been demonstrated before, comparable performance was demonstrated at room temperature. Such performance was not expected based on measurements of upper laser level lifetime as a function of temperature. Lifetime measurements showed a decrease from ≈ 2.0 msec at cryogenic temperatures to ≤ 40 μsec at room temperature. However, the relatively short upper laser lifetime was compensated for by utilizing a short pulse-length pump. A threshold of absorbed pump energy of 40 mJ was demonstrated with a slope efficiency of ≈ 0.4 . To obtain this performance, the Co:MgF₂ laser was pumped with a Nd:YAG laser operating on the 1.33- μm transition. Tuning of the laser was demonstrated using three sets of mirrors to be able to span the extremely wide tuning range. Other spectroscopic work included the measurement of the polarized absorption and emission spectra and the determination of the effective stimulated emission cross section. A commercial produce already has been introduced by the contractor. A prototype laser has been delivered to the solid-state laser laboratory at LaRC for future research.

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New Tunable Infrared Laser for Commercial Market, SBIR Co:MgF₂

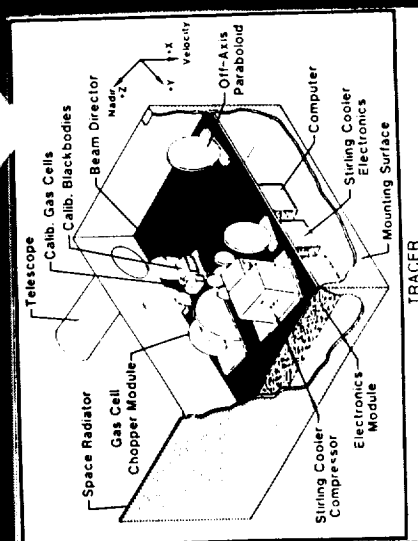
The Science Need:

TROPOSPHERIC CARBON MONOXIDE MAPS EXPERIMENT OCT. 5-13, 1984



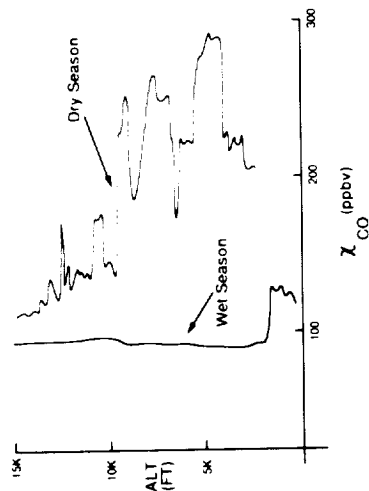
Approved EOS Experiment (Tracer)

Carbon Monoxide Global
distributions impact Global
Change



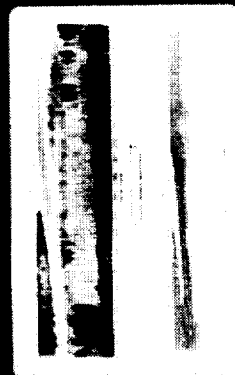
Current OAET Applied Technology

CO Profiles Over the Amazon

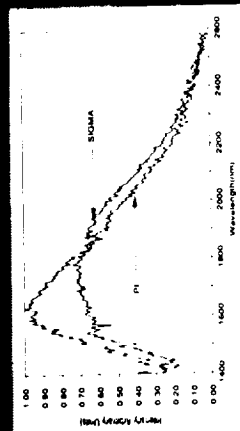


Lead-Salt Diode Laser
Technology (DACOM) provides
Today's Technology
(Developed circa 1978)

Tomorrow: What could be!



• Tunable Laser hits
overtone of carbon
monoxide



(OSSA)
Shuttle MAPS
A/C DACOM

Impact:

High-Temperature Superconductivity Material Applied to Far-Infrared Detector Technology

The Spectroscopy of the Atmosphere Using Far-Infrared Emission (SAFIRE) is an experiment to measure the elusive hydroxyl molecules (OH) in the Earth's atmosphere. It is a Phase-B approved experiment currently planned for the Eos-2 (Earth Observing System). This program is international in scope with LaRC and France responsible for developing detector technology. SAFIRE represents the last step in LaRC's mission to improve man's understanding of the chemistry and dynamics of the Earth's upper atmosphere. The LaRC/LIMS (Lidar Infrared Measurement) Experiment successfully measured the NO_x chemistry on *Nimbus 7*. The LaRC/HALOE (Halogen Occultation Experiment) experiment will obtain global measurements of the ClO_x chemistry and is part of the Upper Atmospheric Research Satellite (UARS) scheduled for launch in 1991.

The LaRC/SAFIRE experiment will obtain measurements of the hydroxyl HO_x groups. In summary, when the spaceflight experiments are complete, three important molecular families will have been measured (NO_x, ClO_x, and OH_x). The SAFIRE instrument is an interferometer-spectrometer experiment that measures thermal emission of upper atmospheric molecules. It requires low-temperature detector technology (4 K) in a high-thermal background. It is a requirement for the success of this project that the low-temperature detector (4 K) be smoothly matched to the preamplifier at 77 K. Because the measurements to be made are extremely finite and sensitive, all distortion and interference must be eliminated or kept to a minimum. To accomplish this task, in part, superconducting material, having no electrical resistance, is being used to link the helium-cooled detector 4 K to the preamplifier (77 K). The superconductivity of state-of-the-art metals has been limited by temperature (less than 70 K). The advent of superconductive ceramic materials has increased the upper limit of superconductivity to 90+ K. The ceramic superconductor being considered for use as a link between the SAFIRE sensor (4 K) and the preamplifier 77 K is also an excellent thermal insulator. This insulation property of a ceramic superconductor, as compared to a metal superconductor, will allow for extending the life of the He reservoir cooling the sensor by preventing a heat leak through the link as shown in the figure.

Since 1987 when the high T_c (95 K) ceramic superconductor materials (Y₁Ba₂Cu₃O_{y-x}) were first developed, major efforts have been under way in many laboratories throughout the world in an attempt to increase the mechanical flexibility of these materials; however, such efforts have met with little success. The Clemson University Ceramic Engineering Department, under sponsorship by LaRC, has developed an alternate approach to the flexible-wire concept which recognizes the inherent brittleness of the superconducting ceramic and attempts to utilize a preformed sintered and tested material by supporting it on a rigid substrate after firing. Superconducting devices made using this technique are, of course, nonflexible and limited to those applications in which forming before firing is appropriate. However, reasonably intricate shapes can be fabricated and have been demonstrated (as shown in the figure).

In addition to the superconductor device produced at Clemson University, the Christopher Newport College Physics Department has developed and is optimizing a low-electrical resistant joint material (10⁻⁶) for use in connecting the ceramic superconductor into the circuit. Successful tests have been performed on typical specimens for thermal shock, moisture sensitivity, and mechanical strength (see the figure).

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High-Temperature Superconductivity Material Applied to Far-Infrared Detector Technology

THE PROBLEM
NEED TO MATCH 4 K DETECTORS
TO 77 K PREAMPLIFIERS



EOS
SAFIRE
EXPERIMENT

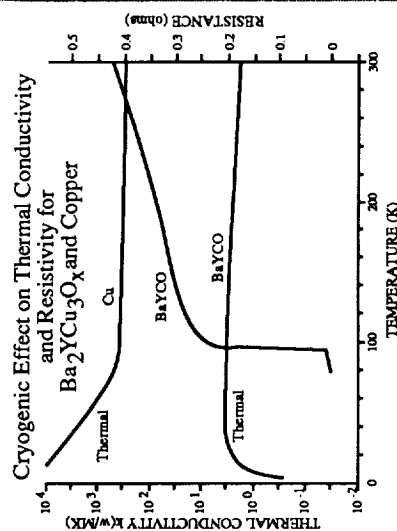
Eos SAFIRE

(APPROVED FOR PHASE B Eos 2)

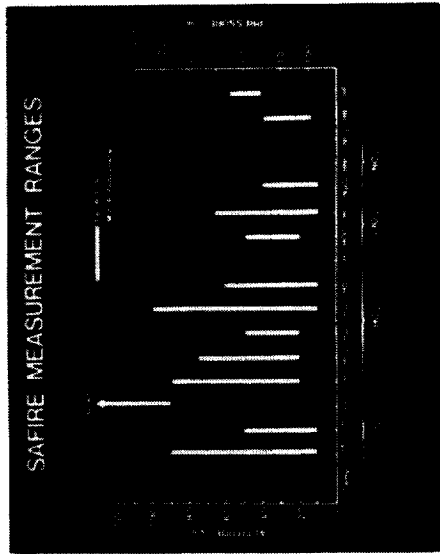


Spectroscopy of the Atmosphere
using Far Infra-Red Emission (SAFIRE)

SAFIRE WILL TACKLE
HYDROXYL MOLECULES



SAFIRE MEASUREMENT RANGES



Submillimeter Wave Sensor Technology Quantum-Well Multiplier Local Oscillator

The research objective of this work is to develop space qualifiable, solid-state sources for use as the local oscillator in submillimeter wavelength heterodyne radiometers employing mixers such as superconductor-insulator-superconductor (SIS) tunnel junctions.

Heterodyne radiometers are employed in remote-sensing applications that require high sensitivity and spectral resolving power such as spectroscopic observations of the interstellar medium, planetary atmospheres, and the Earth's atmosphere. The very important fundamental rotational and vibrational transitions of the more abundant molecular species, including OH, H_3^+ , H_2O , O_2 , and HCl occur at submillimeter wavelengths. Observations from space are required in this spectral region because the atmosphere is nearly opaque. Submillimeter wavelength heterodyne instruments have been identified for the Large Deployable Reflector (LDR), the Submillimeter Infrared Line Survey (SMILS), and the Earth Observing System (Eos) missions.

A single heterodyne mixer requires approximately $100\ \mu\text{W}$ of local oscillator power. Arrays of receivers require proportionately more power. Currently available local oscillator sources in the submillimeter wavelength range are either gas lasers or backward wave oscillators. The operation of gas lasers is limited to specific transitions of gases. In addition, they, along with backward wave oscillators, require large power supplies and critical mechanical tolerances difficult to achieve in a space environment. Solid-state local oscillator sources such as Gunn oscillators are available at lower frequencies in the millimeter wavelength regime. Multipliers employing GaAs Schottky varactor diodes as the harmonic generator driven by these solid-state oscillators have extended them to approximately 400 GHz. Above approximately 400 GHz, no solid-state sources are currently available which meet the output power requirements required to drive heterodyne mixers.

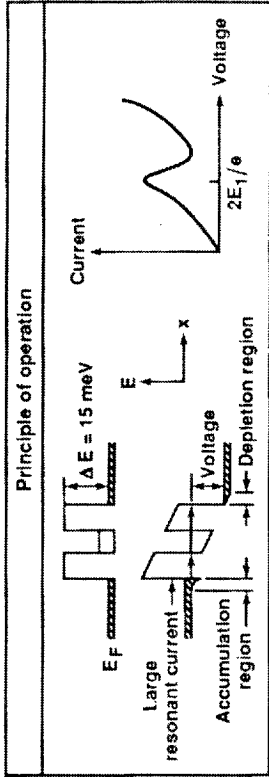
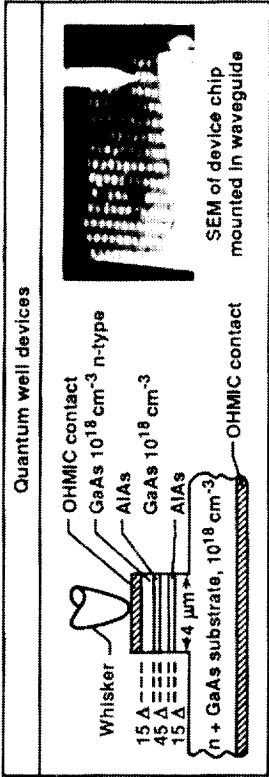
A solid-state local oscillator source (consisting of a multiplier using a quantum-well double-barrier diode as the nonlinear element driven by a Gunn oscillator) is being developed. The current-voltage characteristic of the quantum-well devices exhibits nonlinear behavior including a negative resistance that can be engineered to optimize performance. Because the IV curve is antisymmetric, only odd harmonics are generated thus greatly simplifying the circuit design. The device development is being conducted in collaboration with Lincoln Laboratory; the circuit analysis and development is being conducted at JPL.

Several major advances in the quantum-well local oscillator program have been accomplished. These include the fabrication of resonant structures in InGaAs/AlAs material with cutoff frequencies near 1000 GHz, the measurement at room temperatures of peak-to-valley ratios of 30:1 with a current density of $10^4\ \text{A}/\text{cm}^2$, and the theoretical analysis that indicates that frequency tripling and quintupling efficiencies of 20% can be achieved. Other accomplishments are low-frequency experiments that have reproduced theoretical results, and a waveguide frequency tripler that gives $240\ \mu\text{W}$ of power at 200 GHz.

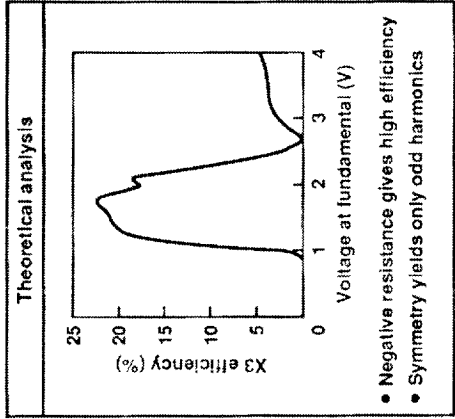
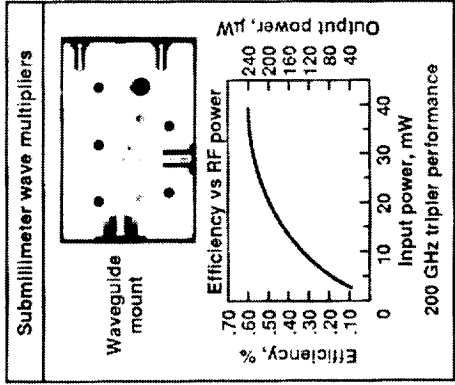
Technical Contact: Margaret A. Frerking, JPL, (818) 354-4902

Quantum-Well Multiplier Local Oscillator

Technical goal	
• Local oscillator source	300-1500 GHz
• Output power	1 μ W-1 mW
• Tunability	10-20%
• Line width	1:10 ⁸
• Frequency stable	1:10 ⁸
• Space qualifiable	



Technical approach	
• Solid state source – quantum well based device	
• Fundamental oscillator	300-600 GHz
• Harmonic generator	600-1500 GHz



Sorption Cooler Technology

The objective of this program is to conduct research leading to the development of space-qualifiable cryogenic sorption coolers suitable for cooling science instrument detectors to temperatures in the 65-K to 140-K range. The basic feasibility of sorption cooler technology has been demonstrated experimentally, but there are numerous technological issues that must be addressed in order to develop sorption cooler technology to the flight-ready level.

Although mechanical Stirling cooler technology has improved over the past few years, it cannot meet the needs of numerous cryogenic science instrument sensors on many future astronomy and Earth observation satellites and platforms. Sorption refrigerators are the only technology that offers the potential to operate reliably for 5 to 10 years with no vibration, electromagnetic interference, or thermophysics effects. The ability of sorption coolers to be easily scalable to a wide range of cooling loads by simply adding or removing compressor modules is another critical advantage over mechanical coolers.

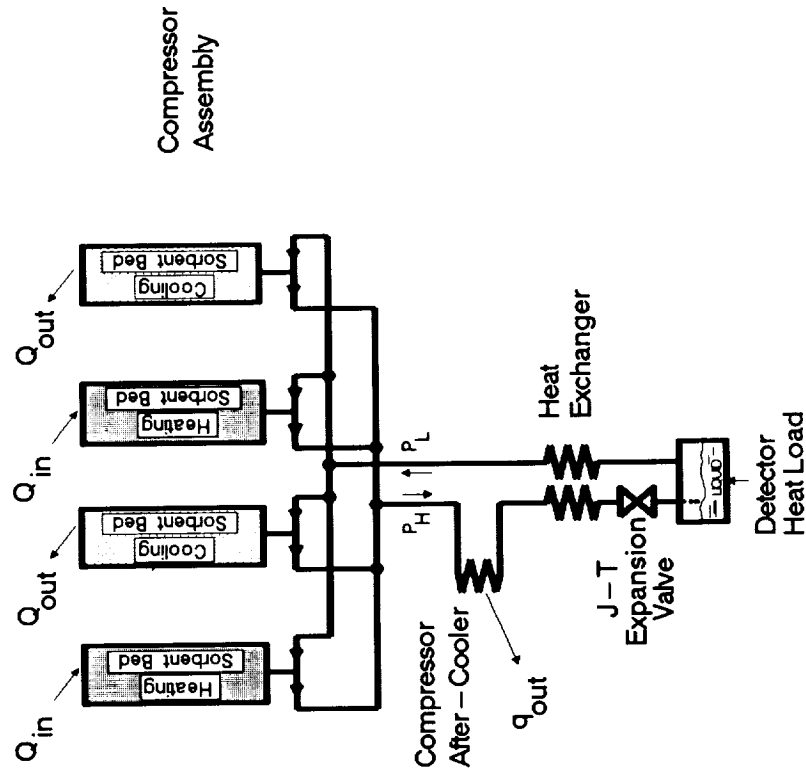
Various sorbent/gas combinations have been studied for different cooling temperature ranges. A 20-K to 30-K hydride/hydrogen (LaNi_5/H_2) chemisorption cooler, a 100-K to 120-K charcoal/nitrogen (C/N_2) physical adsorption cooler, and an 80-K/140-K two-stage sorption cooler have been developed and successfully tested with laboratory breadboard systems at JPL. Recent efforts have concentrated on the latter system, in which the 140-K upper stage is driven by carbon/krypton (C/Kr) physical adsorption compressors, and the 80-K state is driven by praseodymium-cerium-oxide/oxygen (PCO/O_2) chemisorption compressors.

The current thrusts of this research include reliability and improving efficiency. The reliability physics research is focused on investigation of the long-term stability of sorbent materials, the long-term oxidation and creep-rupture properties of candidate compressor container materials, and the parameters controlling the long-term aging behavior of heater elements. The research on improving efficiency is focused on the development of detailed conceptual designs and analyses of sorption compressor heat regeneration systems. Heat regeneration is the process of using the heat rejected by a hotter compressor to raise the temperature of a cooler compressor, thereby decreasing the need for external power. The substantial energy savings obtained from compressor heat regeneration is expected to lead to sorption cooler efficiencies that are comparable to mechanical coolers.

Technical Contact: Ron G. Ross Jr., JPL, (818) 354-9349

BASIC SORPTION REFRIGERATOR CONCEPT

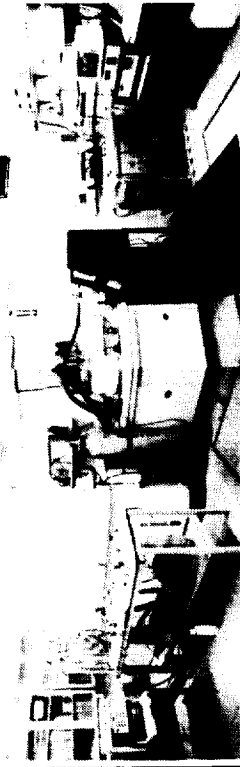
Physical or Chemical Adsorption Processes
Used to Compress Gas for J-T Expander



LAB BREADBOARD PCO/O₂ SORPTION COMPRESSOR COMPONENTS



JPL SORPTION COOLER DEVELOPMENT LABORATORY WITH BREADBOARD 80 K COOLER



Two-Dimensional Acousto-Optic Spectrum Analysis

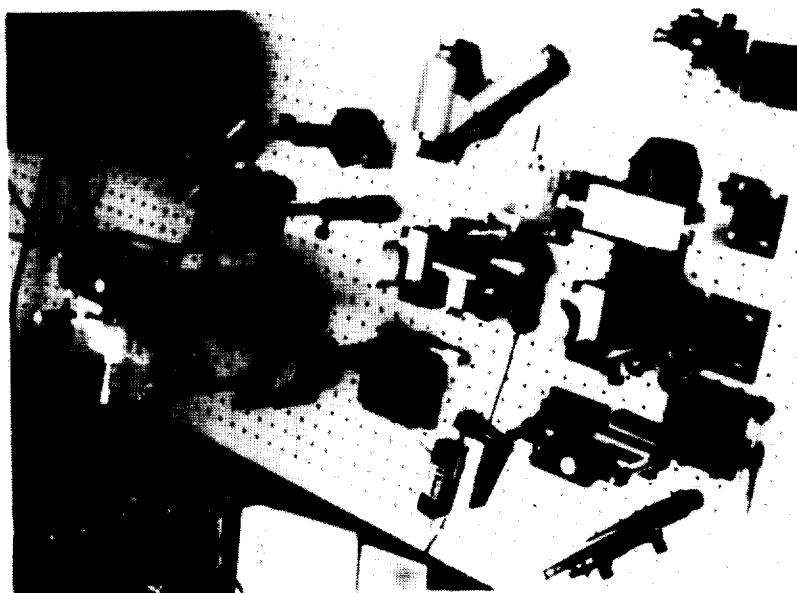
Applications such as Search for Extraterrestrial Intelligence (SETI), radio astronomy, and radar astronomy require analysis of wideband rf signals with high resolution in real time. Optical signal processing techniques are being developed for these applications as an alternative to digital spectrum analysis because of their greatly reduced size, weight, and power requirements.

A two-dimensional acousto-optic spectrum analyzer was developed which combines space and time integration to generate two-dimensional decomposition of signals. A high-speed graphics board was used to generate electronic reference functions required for time integration, and a real-time imaging board was installed to remove spectral bias in the analyzer. A resolution of 150 Hz was thus obtained over an analysis bandwidth of 15 MHz. By using a large format high-dynamic range CCD (charge coupled device) array, the spectrum analyzer has an expected performance of a 30-Hz resolution over one million channels.

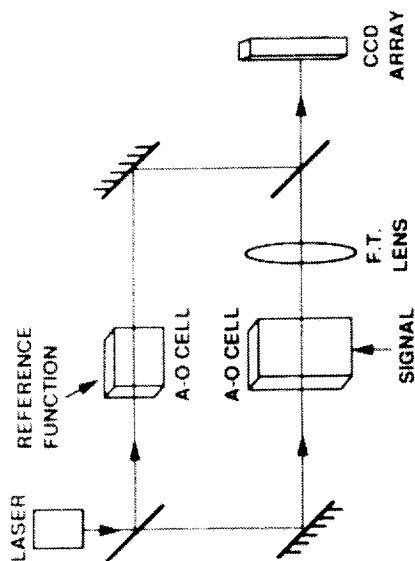
Technical Contact: James R. Lesh, JPL, (818) 354-2766

Two-Dimensional Acousto-Optic Spectrum Analyzer

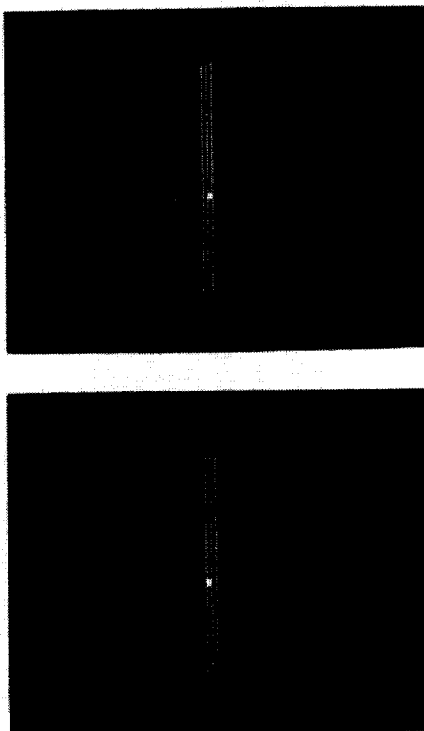
- USES TIME AND SPACE INTEGRATION ARMS TO GENERATE 2D DECOMPOSITION OF SIGNALS
- DEMONSTRATED A FINE RESOLUTION OF 150 Hz OVER AN ANALYSIS BANDWIDTH OF 15 MHz
- EXPECTED PERFORMANCE: FINE RESOLUTION OF 30 Hz OVER 1 MILLION CHANNELS



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ACOUSTO-OPTIC SPECTRUM ANALYZER
INTERFEROMETRIC ARCHITECTURE



FREQUENCY = 10.022 415 MHz FREQUENCY = 10.022 716 MHz

MONITOR DISPLAYS FOR TWO SINGLE TONE SIGNALS

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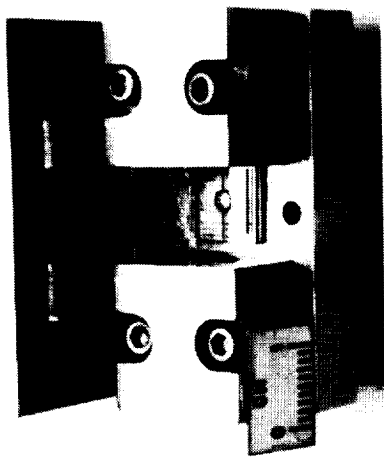
High- T_c Superconducting Microwave Resonator Circuit

The recent discovery of materials that exhibit electrical superconductivity above the liquid nitrogen temperature (77 K) has prompted renewed interest in many potential applications that were previously thought to be economically unfeasible. Many of these applications are in the field of microwave or millimeter wave electronics and include low loss interconnects for complex systems, small-size high- Q filters, small highly efficient directive antennas, low-loss fast efficient microwave integrated circuits, and hybrid superconducting/cooled semiconductor systems.

LeRC has undertaken a program to evaluate the usefulness of microwave circuits that utilize the new high- T_c superconductors. Over the past year, several alternate sources of superconducting films have been developed, substrates appropriate for microwave circuits and compatible with high- T_c films have been identified, lithographic techniques have been put in place, and methods for carrying out rf testing at cryogenic temperatures have been developed. Utilizing these capabilities, a microstrip ring resonator has been built and tested at cryogenic temperatures. The superconducting resonator exhibits a Q approximately twice that of an identical circuit using a gold conductor at the same temperature. Future work will evaluate other passive circuits such as filters, phase shifters, and power dividers by using several film sources and several transmission line structures.

Technical Contact: Kul B. Bhasin, LeRC, (216) 433-3676

High- T_c Superconducting Microwave Resonator Circuit

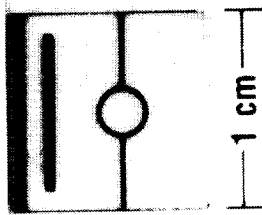


CIRCUIT IN
TEST
FIXTURE

RESULTS:

- CHARACTERIZED FROM 20 K TO RT
- RESONANT FREQUENCY ~ 35 GHz
- "Q" VALUES ABOUT 700 AT 40 K
- APPROX. TWICE BETTER THAN GOLD CIRCUIT AT 40 K

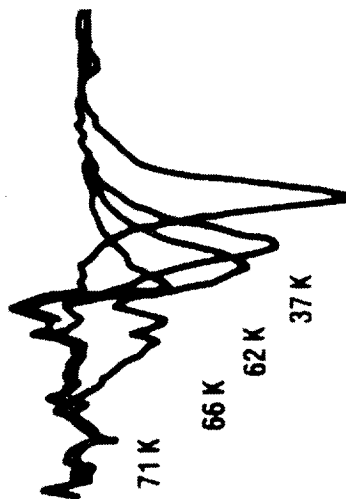
RING RESONATOR CIRCUIT



CHARACTERISTICS:

- Y-Ba-Cu-O FILMS ($1 \mu\text{m}$)
- DEPOSITED BY LASER ABLATION
- LANTHANUM ALUMINATE SUBSTRATE (10 mil THICK, 22 DIELECTRIC CONSTANT)
- FABRICATED BY ADVANCED PHOTOLITHIC GRAPHIC AND ETCHING TECHNIQUES
- CRITICAL TEMPERATURE ($T_c \sim 89 \text{ K}$)

PERFORMANCE



34.6 GHz 35 GHz 35.4 GHz

High- T_c Superconducting Thin-Film Research

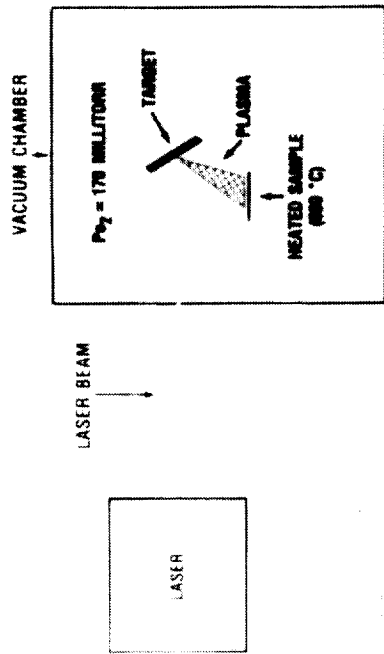
A critical step in the evaluation of high-temperature superconductors for various applications is the development of appropriate materials. For most microwave applications, the requirement is for thin (several μm) films deposited on substrates of low dielectric constant. In addition, the films must exhibit sufficient current-carrying capability.

Over the past year, LeRC has sponsored film deposition research at a number of universities as well as in-house. This has resulted in the production of thin films of several materials by several techniques. These techniques include sequentially evaporated Y-Ba-Cu-O (Ohio State University), coevaporated Y-Ba-Cu-O (Oberline College), laser ablated thallium-based films (University of Nebraska), screen-printed Y-Ba-Cu-O (Case Western Reserve University), and laser ablated Y-Ba-Cu-O (in-house).

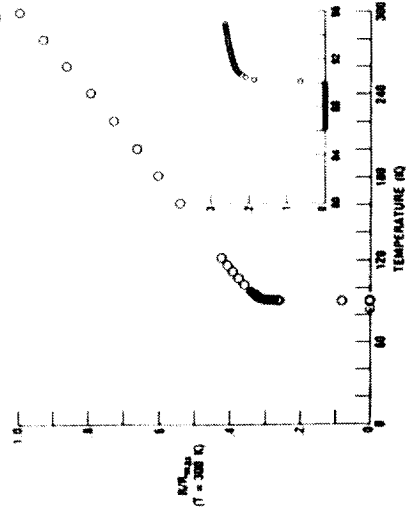
Films from each source have been characterized or used in the fabrication of millimeter wave passive circuits. At this time the highest quality films appear to be those fabricated in-house. These have been oxidized and annealed in situ on a number of useful substrates. They display critical temperatures near 89 K and critical currents of over 1 million amp/cm^2 at 77 K. Thallium-based films developed under grant have achieved T_c near 115 K, but have not yet been deposited on useful microwave substrates. Future work will concentrate on optimizing conditions for deposition and correlating physical characteristics with microwave performance.

Technical Contact: Joseph D. Wagner, LeRC, (216) 433-3677

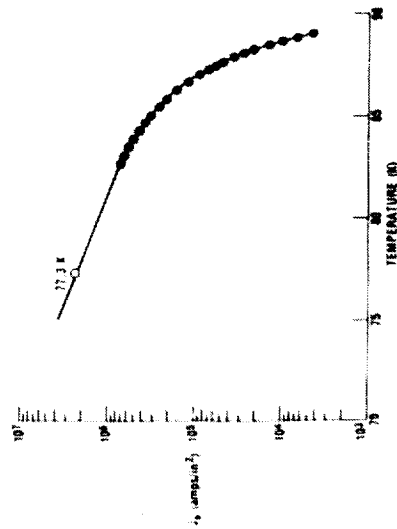
LASER ABLATION TECHNIQUE



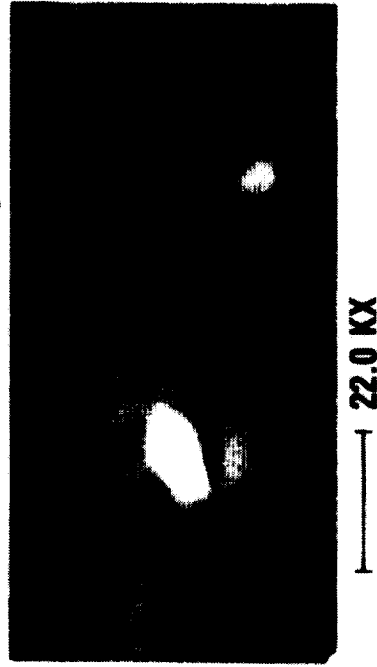
RESISTANCE VERSUS TEMPERATURE OF $YBa_2Cu_3O_7$ FILM ON $LaAlO_3$



CRITICAL CURRENT DENSITY OF $YBa_2Cu_3O_7$ ON $SrTiO_3$



SEM MICROGRAPHS OF $YBa_2Cu_3O_7$ FILM ON $LaAlO_3$



Spaceborne Laser Ranging and Altimetry Components

250

The objective of this program is to develop subsystems and components in support of future NASA laser ranging and altimetry missions such as the Geoscience Laser Ranging System (GLRS) facility on Eos. Current emphasis is placed on two critical GLRS components that include a diode-pumped, subnanosecond pulse Nd:YAG laser transmitter and a space-qualifiable, two picosecond resolution streak camera for precise timing.

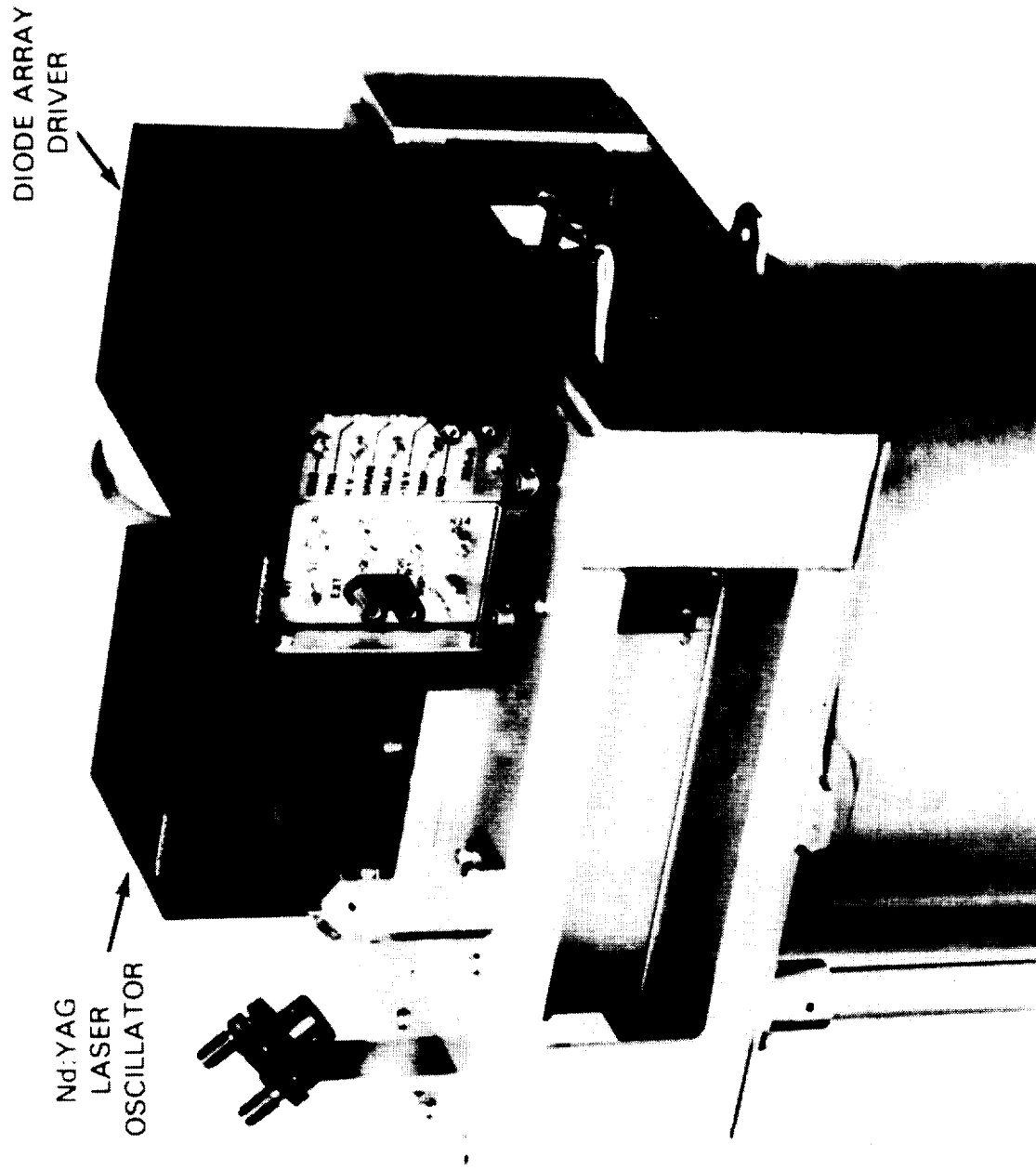
Current NASA programs in geodynamics rely heavily on ground-based technologies such as Satellite Laser Ranging (SLR) and Very-Long Baseline Interferometry (VLBI). Although these systems have produced highly accurate and valuable data for global geodesy and tectonic plate motion studies, their high fabrication and orbiting spaceborne laser ranger, making precise distance measurements to a large number of passive ground-based targets, would provide the spatial and temporal resolution required for highly accurate modeling of tectonic plate motion and regional crustal deformation leading perhaps to a reliable predictor for earthquakes. Subnanosecond pulse lasers and picosecond resolution streak cameras are required to achieve the required subcentimeter accuracies. The ranger utilizes the second and third harmonics of the Nd:YAG transmitter to perform the range measurements. The time delay introduced between the two colors by atmospheric dispersion is measured by the streak camera receiver to convert time of flight to a subcentimeter accuracy distance measurement. The residual Nd:YAG energy is used in a high-precision altimeter for applications in geology, ice processes, and cloud physics.

Concepts for the transmitter and streak camera receiver were developed previously under this program. In the transmitter, a 100-psec pulse is generated at 1064 nm by an Al InP diode laser and injected into a Nd:YAG regenerative amplifier to produce approximately 1 mJ of energy. The pulse is then amplified tenfold in a multipass Nd:YAG preamplifier. In order to achieve maximum efficiency, the amplifiers are pumped at 810 nm by AlGaAs diode arrays.

During fiscal year 1989, 10 linear AlGaAs diode pump arrays were delivered; the pump diode drivers for the 100-picosecond pulse oscillator and upgraded preamplifier were designed, fabricated, and tested; a diode-pumped 1-mJ, 4-nsec-pulse, 100-Hz altimeter laser prototype was developed; the streak camera optical front end was designed, fabricated, and used during LAGEOS II testing; and the remaining components for the 100-psec oscillator were procured. During fiscal year 1990, the spaceborne streak camera feasibility study will be completed, and prototype hardware development will begin. The 100-picosecond-pulse oscillator will be assembled and tested, and the multipass amplifier upgrade will be completed.

Technical Contact: John J. Degnan, GSFC, (301) 286-7714

Diode-Pumped Nd:YAG Laser Altimeter Transmitter



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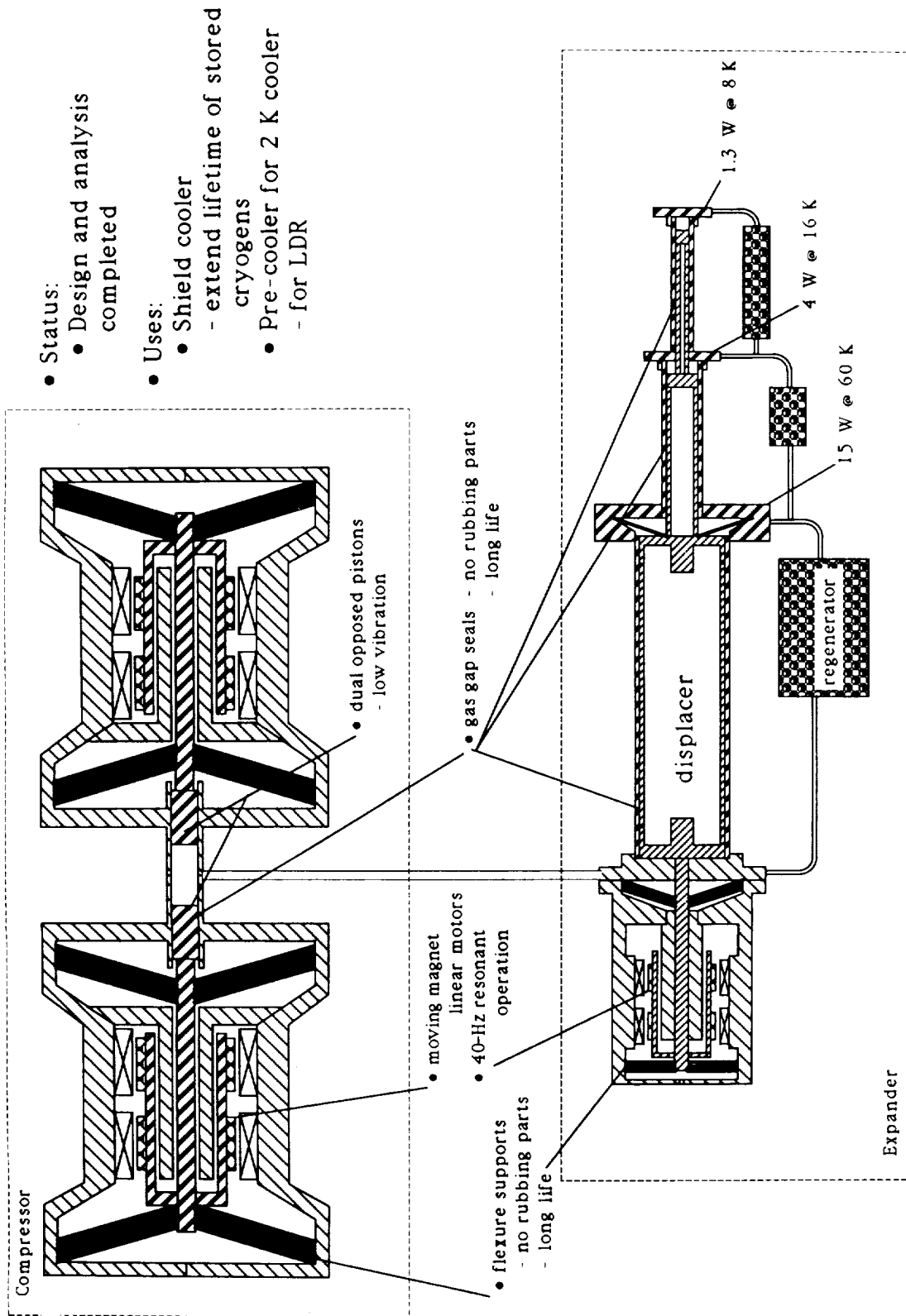
Three-Stage Stirling Cooler for Space Applications

A novel cryocooler for long-lived space applications has been designed by APD Cryogenics. The cooler is intended to be used either as a shield cooler in stored cryogenic systems or as a precooler for a 2-K cooling stage. In the former application, it would be used to intercept the parasitic heat load in a stored liquid helium system, thus reducing the boiloff of the liquid and extending the system lifetime. In the latter application, this cooler would absorb the heat rejected by the magnetic cooling stage. This combined cooler would be used in place of stored liquid helium, thus reducing the mass and volume of the overall system. The Large Deployable Reflector (LDR) is the mission at which this latter cooler is aimed.

Although this cooler draws on previously built coolers, it has several novel features. The cooler uses the linear split Stirling cycle, which allows the compressor and expander sections to be separated on the spacecraft. Long life is achieved by eliminating all rubbing parts. Thus there are no parts to wear out. Narrow gas gaps are used as clearance seals, and flexures are used as bearings. While much of this technology has been used before in small, single-stage coolers (such as the ISAMS cooler on UARS), this cooler advances the technology and power by an order of magnitude. By using three stages of cooling, it will reach almost an order of magnitude lower temperature. The predicted cooling power is 15 W at 60 K, 4 W at 16 K, and 1.3 W at 8 K with 750 W input at 300 K. The low temperature of the third stage is lower than has been achieved by existing Stirling coolers. This is made possible by the use of a novel regenerator made from a lead and stainless-steel composite. The development of this cooler is continuing, and a prototype cooler is under development.

Technical Contact: Peter Kittel, ARC, (415) 694-4297

Three-Stage Stirling Cooler for Space Applications



Tunable Infrared Lidar

The objective of this program is to investigate passive nonlinear optics techniques for generating continuously tunable coherent infrared laser radiation in the wavelength region between $2\text{ }\mu\text{m}$ and $25\text{ }\mu\text{m}$. Specifically, this program investigates the Resonance Enhanced Stimulated Raman Scattering (RESRS) of frequency-doubled alexandrite radiation in cesium atomic vapor and sequential Stokes scattering of the fundamental alexandrite radiation in high-pressure hydrogen cells.

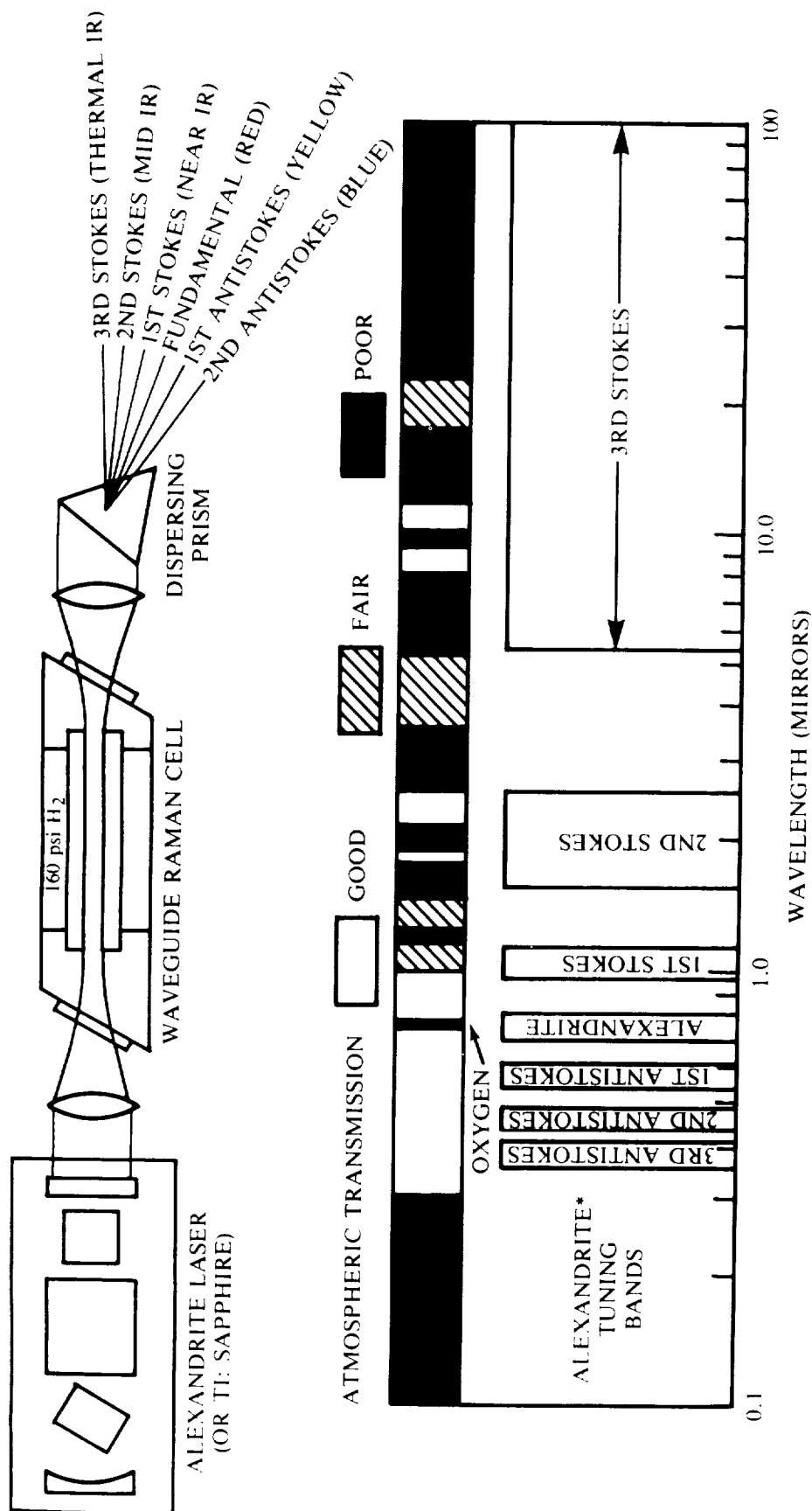
Because most atmospheric molecules of interest have easily identifiable vibration-rotation absorption lines in the wavelength band between $2\text{ }\mu\text{m}$ and $25\text{ }\mu\text{m}$, the latter is often called the "molecular fingerprint region." Furthermore, the existence of atmospheric transmission windows in this same band permits remote sensing of tropospheric trace species from spaceborne platforms. Past lidar systems have often relied on the fortuitous overlap of a narrow laser wavelength with one or more narrow absorption features. The recent development of highly tunable vibronic solid-state lasers permits highly tunable operation in the near infrared. The nonlinear Raman process permits this wide tuning range to be shifted deeper into the infrared through totally passive means to support other trace species measurements important to NASA programs in atmospheric chemistry and global change.

During fiscal year 1989, an extensive theoretical analysis and computer modeling of the three-level process in cesium vapor was completed under a grant to Brown University. The fully diffractive code predicted some unique physical phenomena, such as beam fission in a Raman media, which were observed in subsequent experimentation. The results were published in two doctoral dissertations and several journal articles and conference proceedings in fiscal year 1989. In fiscal year 1990, the grant will experimentally study the impact of injection seeding from a dye laser on Raman output power and stability.

During fiscal year 1989, the alexandrite laser pulse width was reduced by a factor of 4 with a corresponding increase in peak power. A hollow waveguide sequential Stokes Raman cell, filled with high-pressure hydrogen gas, was assembled and tested. This cell greatly extends the nonlinear interaction region in hydrogen by confining the light in a long hollow light pipe. Using 150 mJ of fundamental alexandrite radiation at 755 nm, strong first and second Stokes wavelengths can be successfully generated at $1.10\text{ }\mu\text{m}$ and $2.03\text{ }\mu\text{m}$, respectively. A weak third Stokes component at 12.8 μm and a highly visible first and second Antistokes signals at 574 nm (yellow) and 464 nm (blue), respectively, can also be generated. During fiscal year 1990, an upgrade is planned of the alexandrite system to 700 mJ to permit operation well above the Raman threshold and to develop a computer model of the sequential Stokes process and perform corresponding experimentation in order to optimize generation in the various Stokes orders.

Technical Contact: John J. Degnan, GSFC, (301) 286-7714

Tunable Atmospheric Lidar Using Sequential Stokes Scattering in Hydrogen



*ANY MATERIAL (E.G. TI: SAPPHIRE) WITH A TUNING RANGE EQUAL TO THE STOKES SHIFT ($\Delta\nu = \Delta\nu_s = 4155\text{cm}^{-1}$) CAN TUNE CONTINUOUSLY OVER THE SPECTRUM.

Flashlamp Lifetime

The objective of this program is to develop long-lived flashlamps suitable for use in advanced spaceborne lidar applications. The goal is to achieve lifetimes of 1 to 10 billion shots for three different input electrical energies of 15 J, 50 J, and 100 J. These latter energies are sufficient to pump high-gain (e.g., Nd:YAG), moderate, and low-gain (e.g., alexandrite) laser media, respectively. Although not as efficient as diode pumping, the broad spectral output of flashlamps makes them a universal pump source for several important laser media whose pump bands do not overlap regions in which high-power diode arrays exist. Furthermore, for a given laser output energy, flashlamp pumping is currently three orders of magnitude less expensive to implement than diode pumping.

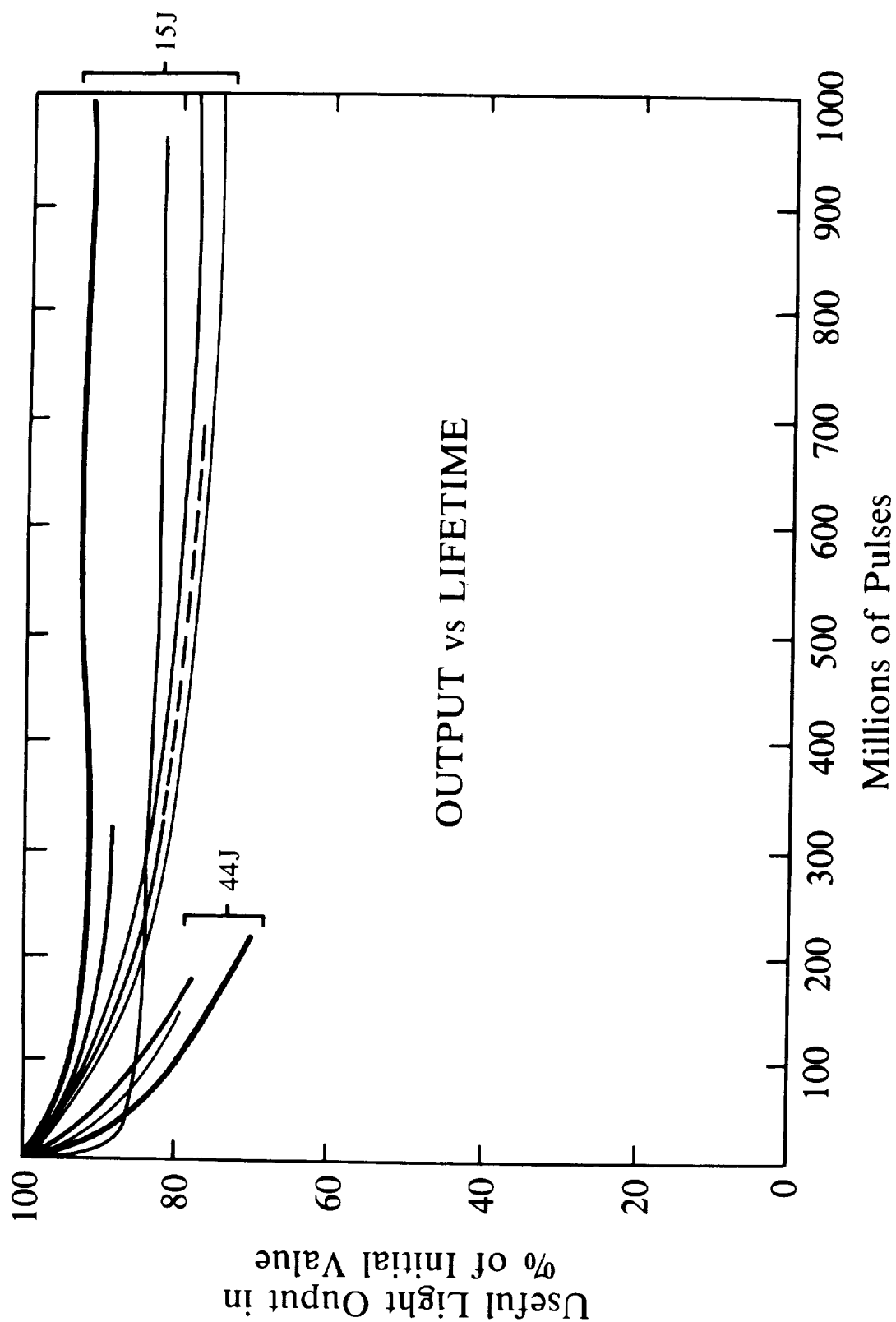
Prior to the initiation of this program in fiscal year 1986, it was generally assumed that flashlamps had a nominal lifetime of about 10 million shots. This assessment was based on early Department of Defense (DoD) lifetime studies carried out in the early 1970's and the general experience of the user population in government and industry. On a few occasions, however, logbook records of lamps used in a commercial laser drilling operation indicated that a few lamps exceeded 100 million shots before requiring replacement. Furthermore, there appeared to be no fundamental physical mechanisms that would prohibit extended lifetimes.

Under this program, a set of standard operating conditions was defined which reflected typical laser pumping requirements, i.e., energy loading and pulse width. Characteristics, such as cathode sputtering deposits, cathode temperature, mechanical integrity, and the fluorescence output of a Nd:YAG sample, were monitored as a function of the number of flashes. Iterative modifications then were made to the lamp design to reduce the amount of cathode sputtering and envelope discoloration and to provide a distributed arc on the cathode.

As of fiscal year 1989, the program has produced a total of four billion-shot laser flashlamps, indicating that the longlife design is reproducible. These lamps were operated with a 15-J single-shot energy at repetition rates to 100 Hz and had not yet reached end-of-life. Also during fiscal year 1989, the moderate energy 50-J lamps achieved over 200 million shots. During fiscal year 1990, emphasis will be on achieving one billion shot lifetimes at 50 J, but two life test stations will be dedicated to testing at the 15-J level beyond one billion shots.

Technical Contact: John J. Degnan, GSFC, (301) 286-7714

Long-Lived Flashlamps for Spaceborne Lasers



LIFETEST RESULTS FOR 15 JOULE AND 44 JOULE LAMPS

Advanced Alexandrite Laser Transmitter

The objective of this task is to develop vibronic lasers suitable for use in future spaceborne lidar missions. Specifically, these lasers must be characterized by high efficiency, long life, ultrahigh-frequency stability, and extremely narrowband operation.

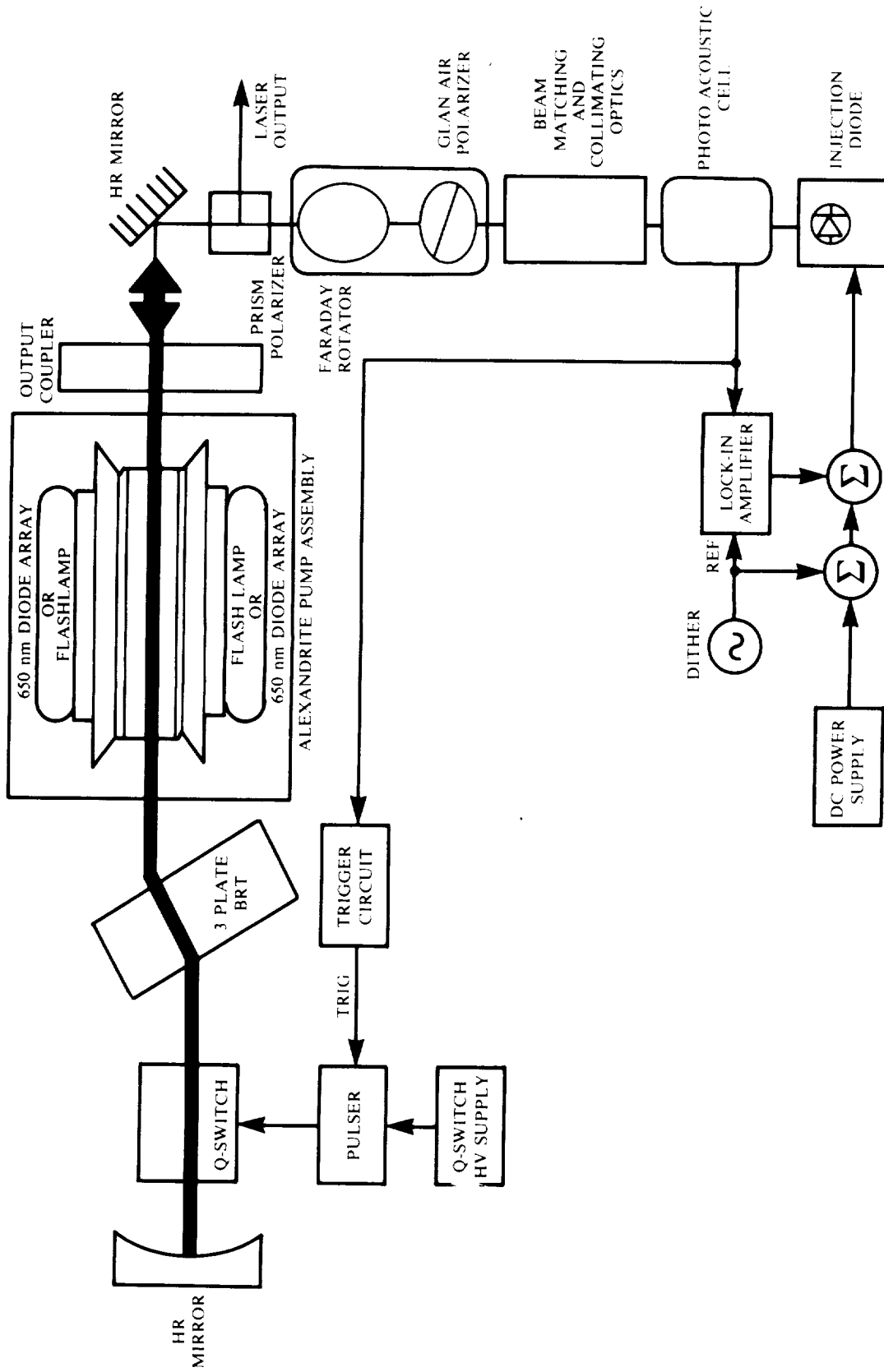
The alexandrite laser material is the most developed of a new class of highly tunable vibronic lasers. Its long fluorescence lifetime, relative to materials such as emerald and titanium-doped sapphire, makes it ideally suited to direct pumping via flashlamp or two-dimensional diode arrays, thereby avoiding the additional complexity, size, and weight of laser-pumped systems. Flashlamp-pumped alexandrite has been used by GSFC to measure atmospheric pressure profiles from the NASA Electra aircraft, and an autonomous flight transmitter is being developed by GSFC under the LASE I program to measure water vapor profiles from the high-altitude Ames Research Center (ARC) ER-2 aircraft. The measurement of atmospheric temperature profiles, as required by the LASE II aircraft program and the Spaceborne Rawinsonde (SPAR) produced for the Earth Observing System (Eos), will require approximately a factor of 4 improvement in both frequency stability and spectral bandwidth relative to the state of the art. In addition, full realization of the alexandrite potential in important spaceborne applications will require major improvements in both efficiency and lifetime.

GSFC published a theory of the optimally-coupled Q-switched laser in the February 1989 issue of the prestigious IEEE Journal of Quantum Electronics. The laser extraction efficiency was found to be a function solely of the ratio of the small signal gain to dissipative optical loss. The latter can be substantially reduced by eliminating the loss line-narrowing etalons in conventional designs and injection-seeding the high-power solid-state laser oscillator with the output of a single-mode diode laser to achieve narrow line operation. The diode laser can in turn be frequency-stabilized to the molecular absorption feature of interest (such as oxygen for temperature) using a photo-acoustic cell and well-known phase-sensitive detection and loop stabilization techniques. A low-loss birefringent tuner internal to the alexandrite oscillator prevents radiation buildup in the high-gain regions of the vibronic transition when operation in a low-gain region is desired. One or more Faraday rotators are used to optically isolate the diode laser from the high-power cavity. In-house calculations, reported previously, indicated that alexandrite pumped by diode arrays could potentially achieve wallplug efficiencies as high as 24 percent (significantly higher than Nd:YAG-pumped Ti:sapphire and much more compact).

During fiscal year 1989, the injection-seeding diode was tested and characterized: a rectangular waveguide photoacoustic cell was designed and fabricated; the remainder of the prototype alexandrite laser and locking components were ordered; and optomechanical design of the flight prototype was begun. During fiscal year 1990, the injection diode will be locked to a molecular oxygen line and injected into the alexandrite power amplifier. Development of short-wavelength (650-nm) diode pump sources will begin via a suballotment to JPL.

Technical Contact: John J. Degnan, GSFC. (301) 286-7714

Advanced Alexandrite Laser Transmitter



Gallium Arsenide (GaAs) Adaptable Programmable Processor (APP)

GSFC has recognized the need to advance the state of the art of onboard high data rate signal processing for future-generation scientific instruments and has chosen for this purpose to develop GaAs integrated circuit technology.

Key requirements in onboard signal processing instruments results from projected increases in information return from Earth-viewing instruments. Advancements in multispectral sensory will produce finer spatial resolution, greater spectral coverage, and consequently greater increased data rates and system bandwidth requirements. The Geodynamic Laser Ranging System (GLRS) will produce surface ice/land topology measurements to finer resolution which will drive onboard high data acquisition and storage technology. Feasibility studies on imaging instruments in support of the Earth Observing Systems have shown increased rates that exceed the telecommunication channel capacity. Onboard signal processing will be necessary in order to utilize the available Tracking and Data Relay Satellite System (TDRSS) communication channel at high efficiency.

The technical approach taken is to develop an eight-bit slice GaAs processor chip set capable of performing high data rate image processing algorithms. The eight-bit slice architecture is a cascaded processing element, specifically designed as a MIL-STD-1750A computer building block, but flexible enough for other applications, such as Reduced Instruction Set Computers (RISC) and signal processors. The initial application for the chip is a signal processing system performing a data compression algorithm. Both the data compression controller and eight-bit slice were fabricated by Rockwell International Corporation. High-speed testing has demonstrated image data compression at 400 Mbits per second. A compression ratio of 2 to 1 was achieved.

A high-speed RAM device is currently under development with an access time of 1.0 nsec, and testing is projected for the second quarter of 1990.

Technical Contact: Warner H. Miller, GSFC. (301) 286-8183

Gallium Arsenide (GaAs) Technology Development

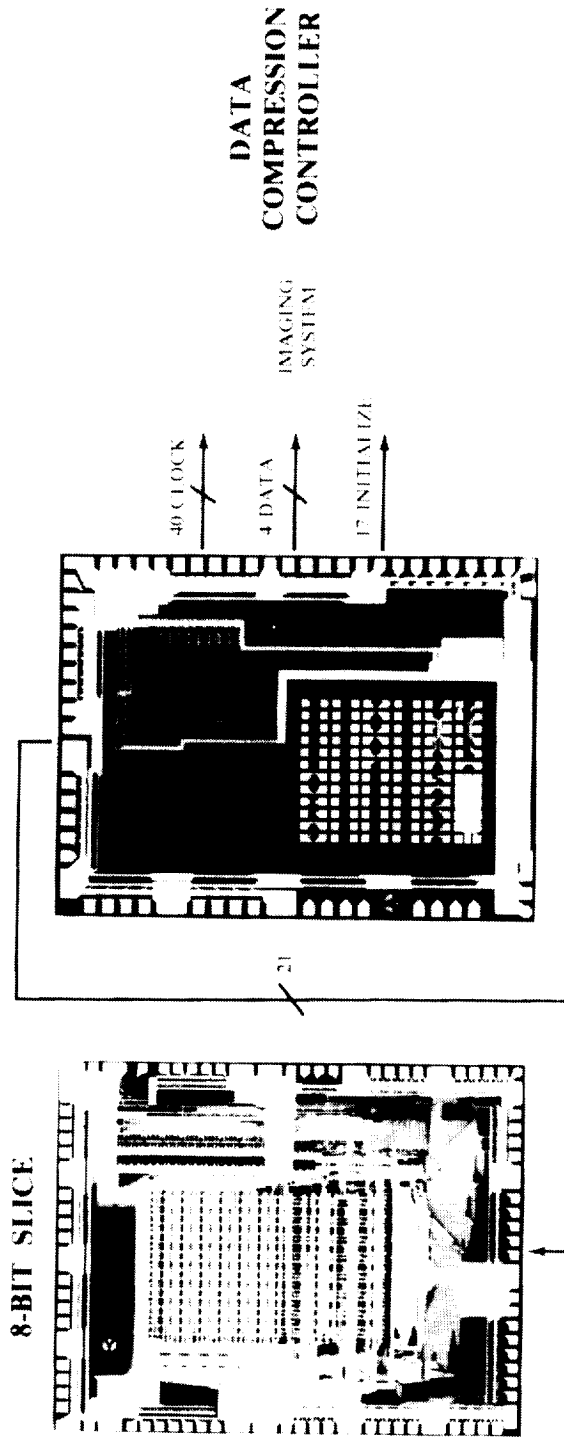
OBJECTIVE:

DEVELOP GaAs INTEGRATED CIRCUIT TECHNOLOGY TO ENHANCE ONBOARD HIGH RATE SIGNAL PROCESSING FOR FUTURE GENERATION SCIENTIFIC INSTRUMENTS.

FY 89 ACCOMPLISHMENTS:

- 8-BIT SLICE PROCESSOR CHIP WAS SUCCESSFULLY TESTED AND THERMAL CYCLED FROM -20 TO +100°C
- BOTH THE 8-BIT SLICE PROCESSOR AND A CONTROLLER CHIP SUCCESSFULLY DEMONSTRATED A DATA COMPRESSION ALGORITHM WITH A COMPRESSION RATIO OF 2 TO 1
- 8-BIT SLICE PROCESSOR CAN PERFORM OTHER ALGORITHMS UTILIZING OTHER CONTROLLER CHIPS

PERFORMANCE RESULTS:



- PERFORM DATA COMPRESSION OF HIRIS IMAGE IN REAL TIME WITH 40% MARGIN PER DETECTOR SIGNAL PORT
- RAD HARD (100M RAD) TOTAL DOSE WITH WIDE OPERATING TEMPERATURE RANGE -200°C TO +200°C
- WORST CASE 8-BIT SLICE GENERAL PROCESSOR OPERATION TIME 6.6 NANOSECONDS

Submillimeter Backward Wave Oscillator

The backward wave oscillator (BWO) is an electron beam device with potential application as a voltage tunable local oscillator for spectrometers deployed above the atmosphere of Earth. The project goal is to produce an oscillator with a frequency up to 1.8 THz.

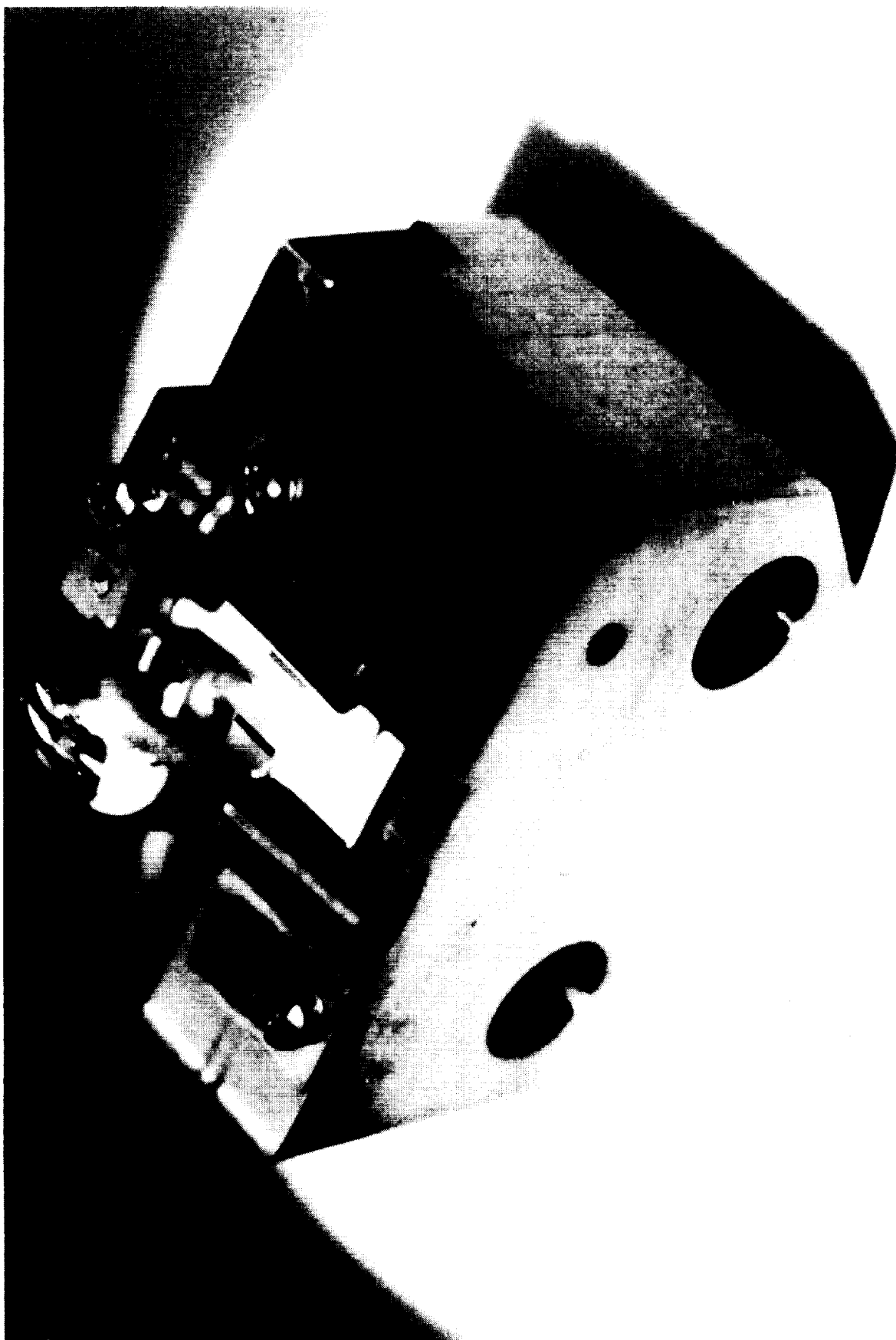
A circuit etched onto a diamond substrate was constructed at Lincoln Laboratory and was installed into the BWO and tested at the University of Utah. Oscillation was immediately observed at beam voltages between 600 V to 5000 V, which correspond to frequencies of approximately 135 GHz to 314 GHz. The data indicated that the bandwidth of the circuit is limited by the design voltage of the electron gun (5 kV).

The circuit is a duplicate of the design that was recently fabricated onto a quartz substrate and which oscillated between 127 GHz to 265 GHz. The higher frequencies shown by the diamond circuit are due to the effective lower dielectric loading caused by etching into the substrate.

The very broad turning range of the BWO is made possible by the use of a quasi-optical output coupler, shown in the figure, which consists of a horn antenna etched into the plane of the slow wave circuit and a sapphire lens that focuses the radiation through the vacuum window.

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Submillimeter BWO With Optical Output Coupler



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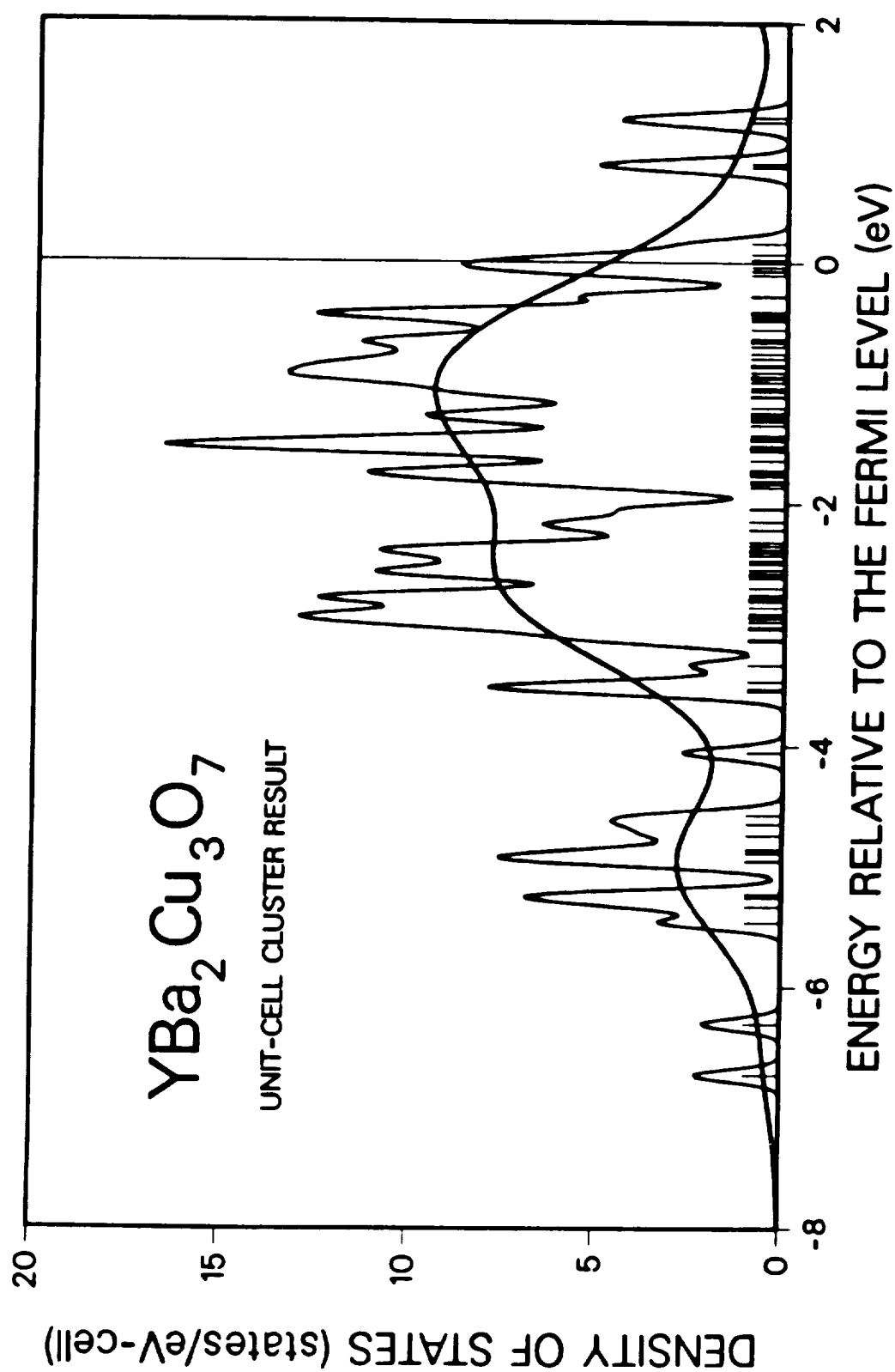
Theoretical Studies of High-Temperature Superconductors

The electrical structure of the 90 K superconductor Y-Ba-Cu-O has been investigated with cluster calculations based on the self-consistent relativistic scattered-wave approach. The validity of the cluster approach has been demonstrated by comparison of the results with solid-state calculations and experimental data. The Cu 3d spin-orbit effects and final state contributions in the photoemission process have been investigated for the first time. After inclusion of the final state effects, the accuracy of calculated core-level energies is within 1 eV to 2 eV, or better than 1 percent. Clusters of the size of a unit-cell give a reasonable description of the system (the surface structure in particular). This will enable the study of surface-related properties and the electronic structure at interfaces.

The figure shows the computed Cu 3d – O 2p related density of electronic states as derived from a $\text{Y}_2\text{Ba}_2\text{Cu}_{12}\text{O}_{18}$ cluster. The peaked and smooth density distributions were obtained by broadening the indicated cluster energy levels with Gaussians using width parameters of 0.05 eV and 0.5 eV. The theoretical spectrum shows the two major maxima observed in photoemission experiments, separated by approximately 2 eV, and additional features at higher and lower binding energies. An analysis of atom-projected partial densities of states shows that the major copper contributions near the center of the double maximum and oxygen contributions more to its sides are in good agreement with energy-dependent X-ray emission experiments that probe these states separately.

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Computed Density of Electronic States for Y-Ba-Cu-O



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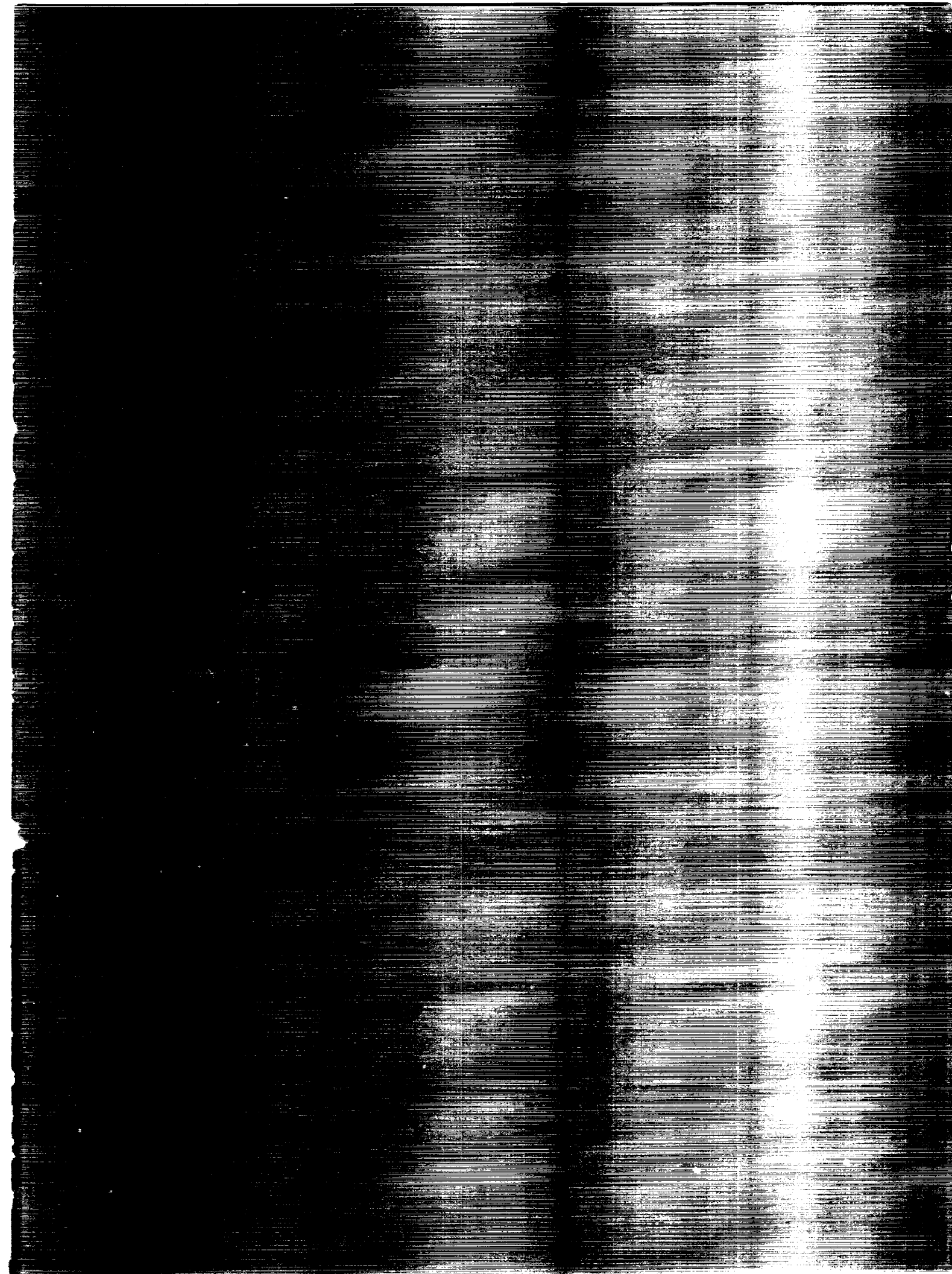
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